Pineview Reservoir TMDL

Prepared by:
Tetra Tech, Inc.

Prepared for:
Utah Department of Environmental Quality
Division of Water Quality

John Whitehead
Project Manager

Harry Lewis Judd
Project Supervisor

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The Pineview Reservoir watershed forms part of the larger Lower Weber River basin in northern Utah. The watershed is entirely located within Weber County, Utah, and is surrounded by the northernmost section of the Wasatch-Cache National Forest. Created in 1937, Pineview Reservoir is an impoundment of the Ogden River at the top of Ogden Canyon. The Ogden River flows through the Wasatch Front, and the Pineview Dam impounds the reservoir in Ogden Valley. Pineview Reservoir is a multipurpose reservoir that provides storage for irrigation water (distributed to farms and residential areas) and culinary water delivered to residents in Weber and Box Elder Counties. The reservoir also provides flood control protection and hydroelectric power generation, and it is well known for its recreational facilities.

The water quality of Pineview Reservoir is generally regarded as good. However, conditions in the late summer months indicate that water quality impairments do exist. Accordingly, the reservoir is listed on Utah's 2000 section 303(d) list for dissolved oxygen (DO), temperature, and total phosphorus (TP). The beneficial use listed as impaired is 3A (cold water aquatic life). Other beneficial uses include culinary water (1C), recreational bathing (2A), boating and similar recreation (2B), and agricultural uses (4). The Clean Water Act and the United States Environmental Protection Agency's (USEPA's) regulations require that Total Maximum Daily Loads (TMDLs) be developed for waters appearing on section 303(d) lists of impaired waters.

The water quality impairments in Pineview Reservoir are believed to be a combination of several factors. First, the watershed is a managed system with water entirely diverted from the tributaries during the irrigation season (April 15 to October 15). This results in groundwater recharge enriched with nutrients being the primary source of water during the summer months. Furthermore, the release of water from Pineview Reservoir for irrigation purposes during the irrigation season has a major effect on water quality. Perhaps most significantly it causes premature breakup of thermal stratification and overturn in August. This occurs earlier than would be expected without the release of water for irrigation and the early mixing results in an increase of nutrients to the photic zone causing an algal bloom, usually in mid- to late-August. Finally, increased development within the valley is believed to be leading to increased nutrient loads from onsite wastewater treatment systems and animal wastes associated with cattle, horses, and sheep.

Because the Utah Department of Environmental Quality (Utah DEQ) has no rules with which to address the impacts of irrigation diversions or management of the reservoir, these potential implementation options have not been explored in any great detail. Instead, this TMDL focuses on the potential benefits of reducing nutrient loads to the reservoir by better treating human and animal wastes, reducing tributary loads, and using more efficient irrigation practices.

This report describes the approach that was taken to estimate current nutrient loads and simulation of reservoir water quality, and identifies necessary load reductions within the context of a TMDL. An initial summary of implementation options is also presented.

1.0 INTRODUCTION

Pineview Reservoir has been placed on Utah's 2000 section 303(d) list of impaired waters because of phosphorus, dissolved oxygen (DO), and temperature (Utah DEQ, 2000). The beneficial use that is impaired is 3A, cold water aquatic life, and the priority for development is high (Table 1). The Clean Water Act and the U.S. Environmental Protection Agency's (USEPA's) regulations require that a Total Maximum Daily Load (TMDL) be developed to identify what actions should be taken to restore the reservoir's beneficial uses. A TMDL is the sum of the allowable amount of a single pollutant that a waterbody can receive from all contributing point and nonpoint sources and still meet water quality standards.

Table 1. 2000 section 303(d) listing information for Pineview Reservoir.

Pollutants or Stressors of Concern	Total Phosphorus, Temperature, Dissolved Oxygen
Beneficial Use Impaired	3A – Cold Water Aquatic Life
Priority for TMDL	High
Hydrologic Unit Code	16020102
Reservoir Size	2,874 acres

1.1 Watershed Location

The Pineview Reservoir watershed forms part of the larger Lower Weber River Basin (USGS Hydrologic Unit Code 16020102). The watershed is entirely located within Weber County, Utah, and is surrounded by the northernmost section of the Wasatch-Cache National Forest (Figure 1). Created in 1937, the reservoir is an impoundment of the Ogden River at the top of Ogden Canyon. The Ogden River flows through the Wasatch Front, and the Pineview Dam impounds the reservoir in Ogden Valley. Pineview Reservoir is a multipurpose reservoir that provides storage for irrigation water (distributed to farms and residential areas) and culinary water delivered to residents in Weber and Box Elder Counties. The reservoir also provides flood control protection and hydroelectric power generation, and it is well known for its recreational facilities.

The land immediately adjacent to Pineview Reservoir became part of the National Forest System by an Act of Congress in 1940. The land was placed under Forest Service administration to protect the soil resource, preserve water quality, protect private land, and provide recreational opportunities. There are 287 hectares (710 acres) of land within this "buffer zone," which varies from several feet to several hundred feet in width.

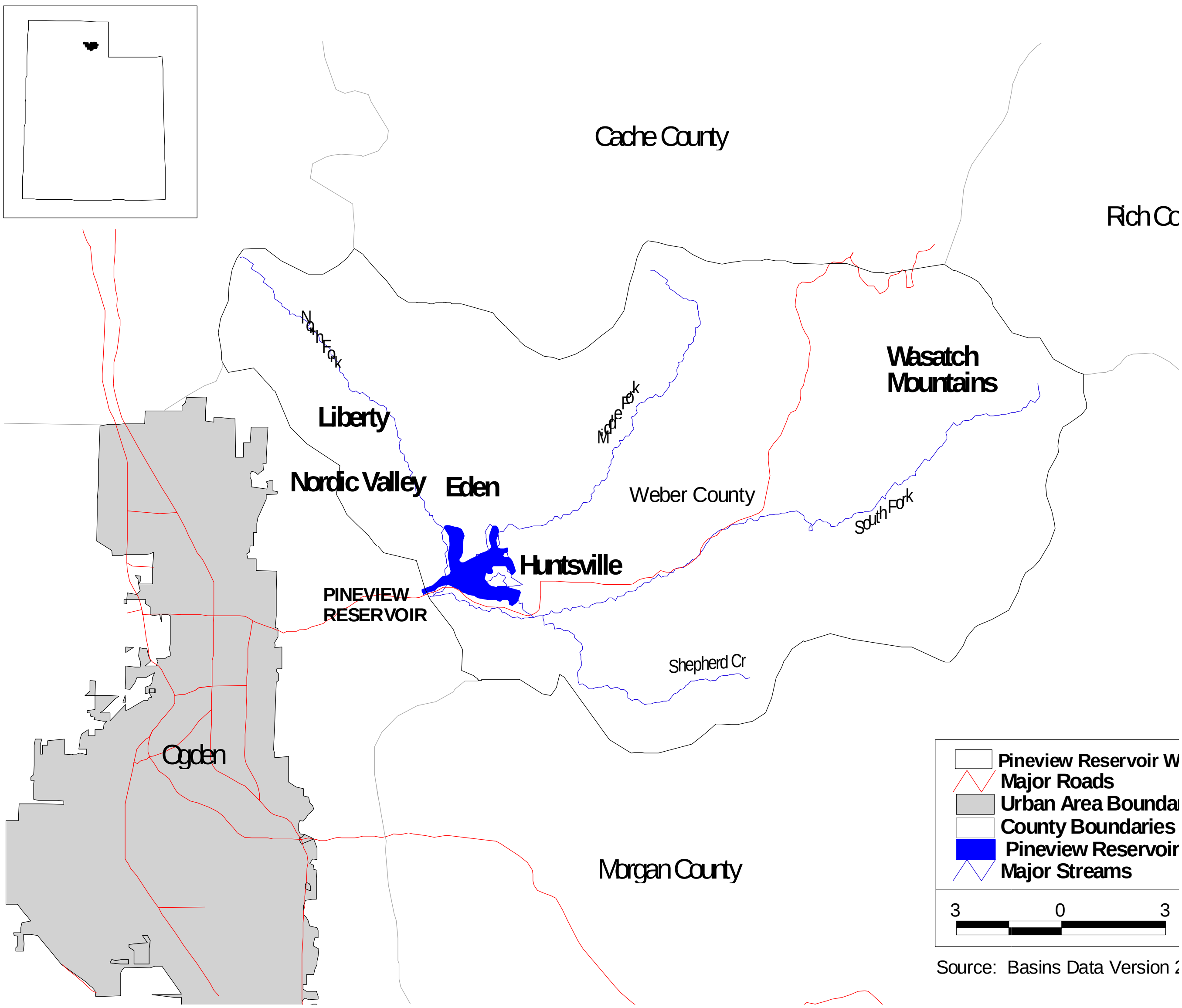

Figure 1. Political boundaries, roads, and location of Pineview Reservoir.

1.2 Population

Weber County has a population of 196,533, mostly concentrated around the urban center of Ogden City (U.S. Census Bureau, 2000). Since 1990 the county has experienced a 24 percent increase in population, although building permits issued in the first 9 months of 2001 were down considerably (12.9 percent) from the same period in 2000 (Standard Examiner, 2001).

Ogden Valley, which consists of the communities of Liberty, Eden, Nordic Valley, and Huntsville, has a collective population of approximately 6,600. The population of the town of Huntsville itself has increased by 16 percent in the past 10 years, going from 561 residents in 1990 to 649 in 2000 (U.S. Census Bureau, 2000).

Historically the valley has been largely agricultural, with many of the residents raising livestock (horses in particular) and growing hay and alfalfa for feed. However, agriculture is decreasing in the valley as a result of increasing tourism and new summertime residents. Weber County saw a 68 percent decrease in land used for farming from 1992 to 1997 (USDA, 1997). Increased development has accompanied the downturn in farming. The new developments include ski resorts, golf courses, and new residential areas in the vicinity of the Pineview Reservoir, as well as on the lower slopes of the Wasatch Mountains, west of the reservoir. A significant number of horse farms are still present in the valley.

1.3 Topography and Land Use

The Pineview Reservoir watershed consists of high mountains, foothills, terraces, and mountain valleys. The high point, Willard Peak, is 2,976 meters (9,764 feet) above sea level. The watershed is located in the Wasatch and Uinta Mountains ecoregion, where coniferous forests predominate. Historical land uses in this ecoregion include grazing, logging, mining, and recreational activities.

Currently land use in the Pineview Reservoir watershed is a mix of forest, rangeland, and agriculture. The land cover for the region, shown in Table 2 and Figure 2, was extracted from the Multi-Resolution Land Characterization (MRLC) database for the state of Utah (MRLC, 1992). This database is derived from satellite imagery taken during the early 1990s. Each 30- by 30-meter pixel contained with the satellite image is classified according to its reflective characteristics. The classification “shrubland” is defined as areas dominated by shrubs or where shrub canopy accounts for 25 to 100 percent of the cover. It is assumed that shrub cover is generally greater than 25 percent in areas where tree cover is less than 25 percent.

Table 2. Land use distribution by major land use category (MRLC, 1992).

	Area (hectares)	
Shrubland	40,584	52.24
Grasslands/herbaceous	17,341	22.32
Forested upland	13,652	17.57
Cultivated	3,772	4.86
Open water	1,166	1.50
Wetlands	1,108	1.43
Barren	37	0.05
Developed	21	0.03
Total	77,681	100.00

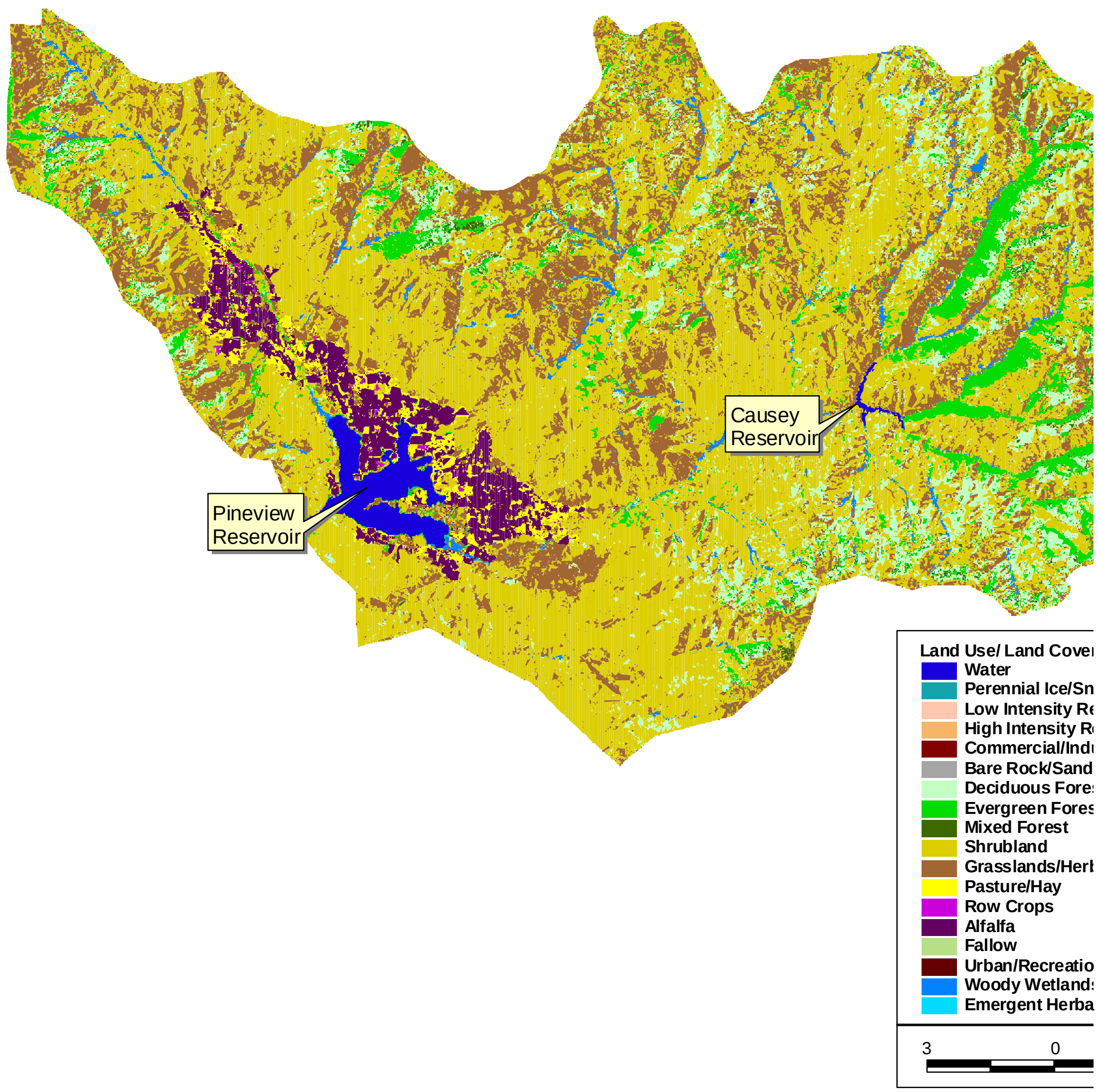

Figure 2. 1992 MRLC land use for the Pineview Reservoir watershed.

Because the satellite imagery available for the watershed dates to the early 1990s, there have likely been some changes in land use. At the TMDL public meeting on August 9, 2001, local residents reported that some of the land that is currently classified as cultivated is probably now residential land. Some of the residential land in the watershed is also probably misclassified as shrubland or grassland. This occurs because the housing density is so low that the image is not fine enough to detect a structure on the large lot sizes.

1.4 Climate

The climate of northern Utah is dry with about 265 days of sunshine a year. Summers are hot and dry, and winters are cold and dry. The bulk of winter moisture comes as snowfall. Based on the substantial differences in elevation within the watershed, precipitation patterns are markedly different from one area to another. Average annual precipitation ranges from 20 to 50 inches, and the highest mountainous areas receive the highest precipitation totals. As is the case with many western watersheds, annual precipitation totals vary dramatically. Figure 3 displays the monthly average precipitation data for the station at the Huntsville Monastery from 1977 to 2000 (WRCC, 2001).

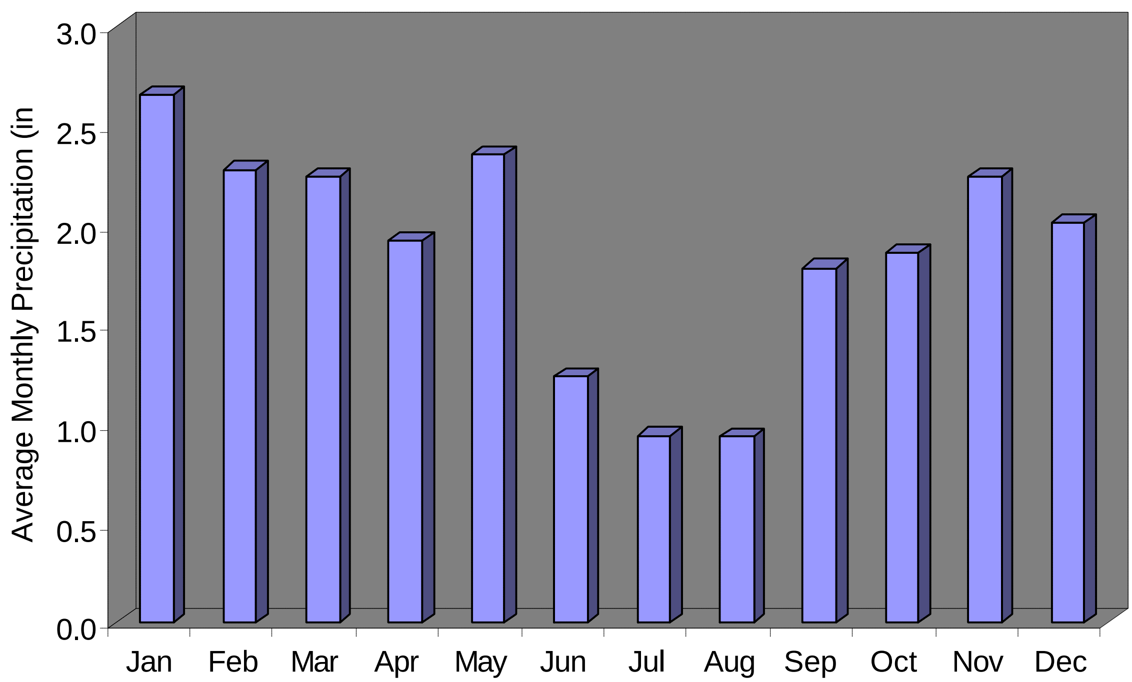

Figure 3. Average monthly precipitation at the Huntsville Monastery (1977 to 2000).

The Wasatch and Uinta ecoregions are relatively more arid than other Rocky Mountain ecoregions. This is a result of the rain shadow cast by the Sierra Nevada mountains (800 kilometers west), which prevent moist air from penetrating from the southwest or southeast. The higher peaks nevertheless receive a significant amount of snow. Snow accumulation and melt is a very significant feature in terms of the annual hydrologic cycle for this watershed. The average total snowfall is about 302 centimeters (119 inches).

Normal maximum and minimum temperatures in Northern Utah are !0.5 °C (31 °F) and !13.3 °C (8 °F) in January and 30.6 °C (87 °F) and 10.6 °C (51 °F) in July (WRCC, 2000).

1.5 Reservoir Hydrology

Pineview Reservoir is part of the Ogden River Project, which uses stream flows in the Ogden River watershed for multiple purposes, including irrigation, flood control, and municipal water supply. Two project reservoirs, the Causey and Pineview (Figure 1), regulate the flow of the Ogden River before it emerges from the mountains to join the Weber River. The Causey Reservoir is on the South Fork of the Ogden River, about 11 miles upstream from the Pineview Reservoir. It provides irrigation water for mountain valley lands near Huntsville and Eden.

The water stored by Pineview Reservoir provides irrigation water to 25,000 acres of agricultural land located between the Wasatch Mountains and the Great Salt Lake. The Pineview Dam is located in the Ogden River Canyon about 7 miles east of the city of Ogden. It currently has a maximum storage capacity of 110,150 acre-feet. Pineview Water manages the first 40,000 acre-feet of the water in the reservoir, and the Weber Basin Water Conservancy District manages the next 60,000 acre-feet (Miner, 2001).

Important physical characteristics of the reservoir are identified in Table 3. Snowmelt fills the reservoir during the spring thaws with a maximum volume typically reached in June. During irrigation season (April 15 to October 15) the reservoir is operated for irrigation and drinking water purposes with controlled releases of stored water according to the needs of the water rights holders.

Table 3. Physical characteristics of Pineview Reservoir.

Elevation	1,493 m (4,900 ft)
Dam Height	41.76 m (137 ft)
Maximum Surface Area	1,163 ha (2,874 ac)
Maximum Volume	135,868,000 m^3 (110,150 ac-ft)
Maximum Depth	24.7 m (81.04 ft)
Mean Annual Drawdown	32,330,085 m^3 (26,210 ac-ft)

Source: WBWQMD, 1990.

Thermal stratification, or layering, occurs in many Utah reservoirs. Whether or not a reservoir stratifies depends on a number of factors: the shape and depth of the reservoir, the amount of wind, and the orientation of the reservoir (reservoirs that are oriented east-west are more affected than reservoirs oriented north-south). When layering occurs the upper, warmer layer is referred to as the epilimnion, and the colder, deeper layer is referred to as the hypolimnion. The boundary between the layers where the rate of temperature change is most rapid is referred to as the thermocline. Temperature stratification is often paralleled by stratification of other water quality measurements such as pH and DO.

The DO concentration in the epilimnion typically remains high throughout the summer because of photosynthesis and diffusion from the atmosphere. However, conditions in the hypolimnion vary with trophic status. In eutrophic (more productive) lakes, hypolimnetic DO declines during the summer because it is cutoff from all sources of oxygen, while organisms continue to respire and consume oxygen. The bottom layer of the lake and even the entire hypolimnion may eventually become anoxic, that is, totally devoid of oxygen. In oligotrophic lakes, low algal biomass allows deeper light penetration and less decomposition. Algae are able to grow relatively deeper in the water column and less oxygen is consumed by decomposition. The DO concentrations may therefore increase with depth below the thermocline where colder water is “carrying” higher DO leftover from spring mixing (oxygen is more soluble in colder water). These differences between eutrophic and oligotrophic lakes tend to disappear with fall turnover.

Pineview Reservoir normally begins to stratify in early June, becoming strongly stratified by late June to early July (WBWQMC, 1990). The South and North Forks of Pineview Reservoir are relatively shallow and only become weakly stratified. Typically the release of water from Pineview Reservoir for irrigation has a major effect of breaking up the thermal stratification, causing overturn in August (earlier than would occur without the release of water for irrigation). By the end of August the reservoir typically has completely overturned. This early mixing results in an increase of nutrients to the photic zone, causing an algal bloom in mid- to late August. Several residents of the valley indicated during the January 10, 2002 public meeting that the algal blooms have become worse during the past couple of years (although there are no data to confirm this).

1.6 Watershed and Stream Hydrology

During parts of the year the Pineview Reservoir watershed has three primary surface water inflows: the South Fork Ogden River (which contributes 73 percent of the total surface flow in the Ogden Valley), the Middle Fork Ogden River (which contributes 19 percent), and the North Fork Ogden River (which contributes 8 percent). The Weber Basin Water Conservancy District operates a major irrigation diversion on the South Fork of the Ogden River. This structure regulates stream flow and distributes irrigation water to four major canal systems. During the irrigation season (April 15 to October 15), natural stream flows and releases from Causey Reservoir are diverted into the Mountain Valley Canal, Co-op Canal, Huntsville South Bench Canal, and the Huntsville pressure system. Since there are no minimum stream flow requirements below the diversion, the South Fork channel is essentially dry for several miles until groundwater recharge replenishes stream flow.

Stream flows in the Middle Fork drainage are regulated for irrigation. During the irrigation season the Middle Fork is totally diverted into the Mountain Valley Canal and Middle Fork irrigation systems. The only stream flow reaching Pineview Reservoir after the initial spring runoff is returned groundwater recharge (PBWQC, n.d.).

The eastern slopes of Ben Lomond Peak are the main drainage areas of the North Fork of the Ogden River. Seasonal flows are controlled by Utaba Reservoir. Springs and surface flows provide water for the Liberty pipeline and Cobble Creek culinary water systems. Stream flows in the North Fork below Utaba Reservoir are intermittent due to the irrigation season and return groundwater flows. Generally below the irrigation diversion the stream is totally dry during the summer months (PBWQC, n.d.).

Groundwater in the watershed occurs in perched, confined and unconfined aquifers in the valley. Consolidated Proterozoic and Paleozoic rocks underlie the valley fill, but the depth to bedrock is generally unknown. The confined aquifer underlies the western portion of the Ogden Valley. Before the construction of the Pineview Reservoir, the aquifer discharged near the Ogden Canyon because of stream erosion. However, the manner in which the reservoir dam was constructed makes it unlikely that significant discharge occurs at present (WBWQMC, 1990).

The U.S. Geological Survey (USGS) has collected stream flow data at seven locations in the Pineview Reservoir watershed. Only one of these is still active. Summaries of the drainage area and average discharge for these stations are presented in Table 4. The flow record for the one current gage in the watershed, the South Fork gage, is shown in Figure 4. The South Fork gage is located downstream from a diversion junction. Water that is stored in the Causey Reservoir is diverted during irrigation season. Therefore the flows during the irrigation season are groundwater recharge flows.

Table 4. Flow statistics at USGS gaging stations.

		Period of Record	Drainage Area (mi^2)	Avg. Discharge (ft^3/s)
10137500	South Fork Ogden River Near Huntsville	1921–2001	137.00	115.60
10137900	Spring Creek at Huntsville	1958–1987	7.20	10.16
10137800	Middle Fork Ogden River at Huntsville	1958–1965	32.90	22.17
10137780	Middle Fork Ogden River Above Diversion Near Huntsville	1963–974	31.30	31.83
10137700	North Fork Ogden River Near Huntsville	1959–1965	61.40	35.30
10137680	North Fork Ogden River Near Eden	1963–1974	6.03	12.09
10137600	South Fork Ogden River at Huntsville	1959–1965	170.00	77.78
10140100	Ogden River Below Pineview Reservoir Near Huntsville	1988–1999	323.00	117.90

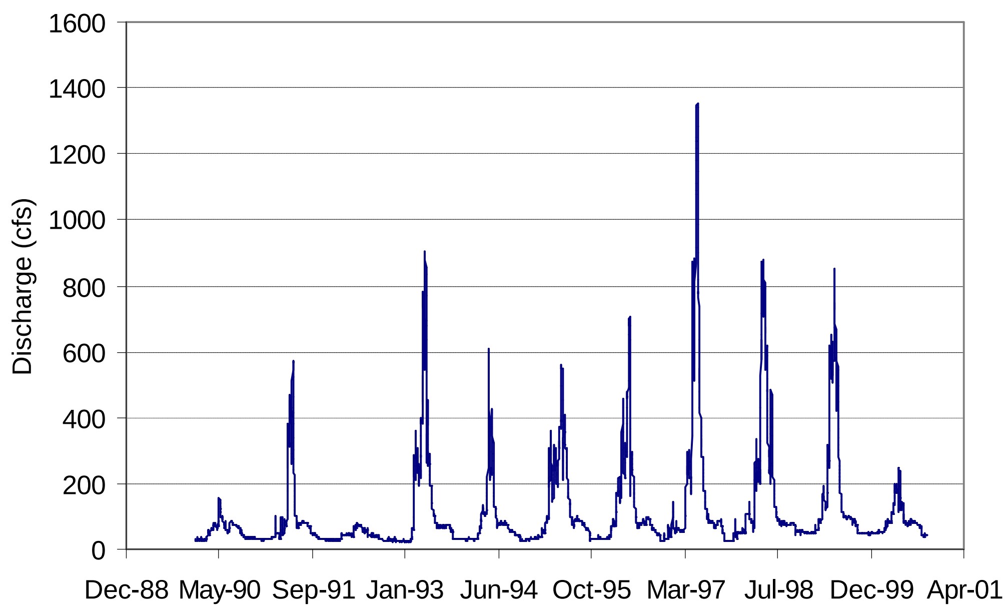

Figure 4. Flow record for South Fork Ogden River near Huntsville, Utah.

2.0 WATER QUALITY STANDARDS

States are responsible for setting water quality standards to protect the physical, biological, and chemical integrity of their waters. The three components of water quality standards include:

- Beneficial uses (e.g. drinking water supply, aquatic life protection, recreation)
- Narrative and numeric criteria designed to protect these uses
- An antidegradation policy that provides a method of assessing activities that might affect the integrity of waterbodies.

The overall water quality of Pineview Reservoir is generally regarded as good. However, water quality data show that water quality impairments do exist in the late summer months. Accordingly, the reservoir is listed on Utah's 2000 section 303(d) list for DO, temperature, and total phosphorus (TP). The beneficial use listed as impaired is 3A (cold water aquatic life). Other beneficial uses include culinary water (1C), recreational bathing (2A), boating and similar recreation (2B), and agricultural uses (4).

Even though the reservoir is officially designated as a cold water fishery, it is being managed as a warm water fishery. The Division of Wildlife Resources indicated that Pineview Reservoir is a "world class" warm water fishery and there are no plans to go back to managing it as a cold water fishery (Schaugaard, 2001). The temperature criteria for cold water fisheries is 20 °C while the criteria for warm water fisheries is 27 °C.

Table 5 describes the water quality criteria that apply to Pineview Reservoir for the three listed parameters for each of its beneficial uses. The sections below discuss how these criteria are interpreted to make use-support decisions and describe the available data for the reservoir.

Table 5. Water quality criteria for Pineview Reservoir beneficial uses.

Beneficial Use				
1C	Domestic purposes	—	—	—
2A	Recreational bathing	—	—	0.025
2B	Boating and similar recreation	—	—	0.025
3A	Cold water aquatic life	Max.: 20 ºC Max. change: 2 ºC	30-day avg: 6.5 7-day avg: 9.5 7-day min: 5.0 1-day avg: 8.0 1-day min: 4.0	0.025
4	Agricultural use	—	—	—

2.1 Dissolved Oxygen

Like terrestrial animals, fish and other aquatic organisms need oxygen to live. As water moves past their gills, microscopic bubbles of DO gas in the water are transferred from the water to their blood. Like any other gas diffusion process, the transfer is efficient only above certain concentrations. In other words, oxygen can be present in the water, but at too low a concentration to sustain aquatic life. The water quality criteria in Table 5 are intended to ensure that sufficient DO is available to support the desired aquatic life.

The Utah Department of Environmental Quality (DEQ) has historically used the 1-day minimum DO concentration of 4.0 mg/L to make use support decisions. When the concentration is above 4.0 mg/L for greater than 50 percent of the water column depth a fully supporting status is assigned. When 25 to 50 percent of the water column is above 4.0 mg/L a partially supporting status is assigned, and when less than 25 percent of the water column exceeds the 4.0 mg/L criteria, a not supporting status is assigned.

The Utah DEQ samples four stations in Pineview Reservoir (Figure 5). Station 492381 (above the dam) is used to make use support decisions in Pineview Reservoir. The percent of samples for station 492381 that are greater than 4.0 mg/L are shown in Table 6 and the observed data are plotted in Figure 6. Data at the other stations show a similar pattern.

Table 6. Observed DO conditions for Pineview Reservoir (measured at station 492381).[1]

Date	Percent of Samples Greater Than 4.0 mg/L	Support Rating
6/19/1996	95	Supporting
8/6/1996	32	Not Supporting
7/23/1998	100	Supporting
8/25/1998	48	Not Supporting
6/1/2000	95	Supporting
8/2/2000	58	Supporting

[1] This information has changed slightly from earlier reports because it was determined that there was an error with the original raw data.

Figure 5. Utah DEQ sampling stations in Pineview Reservoir.

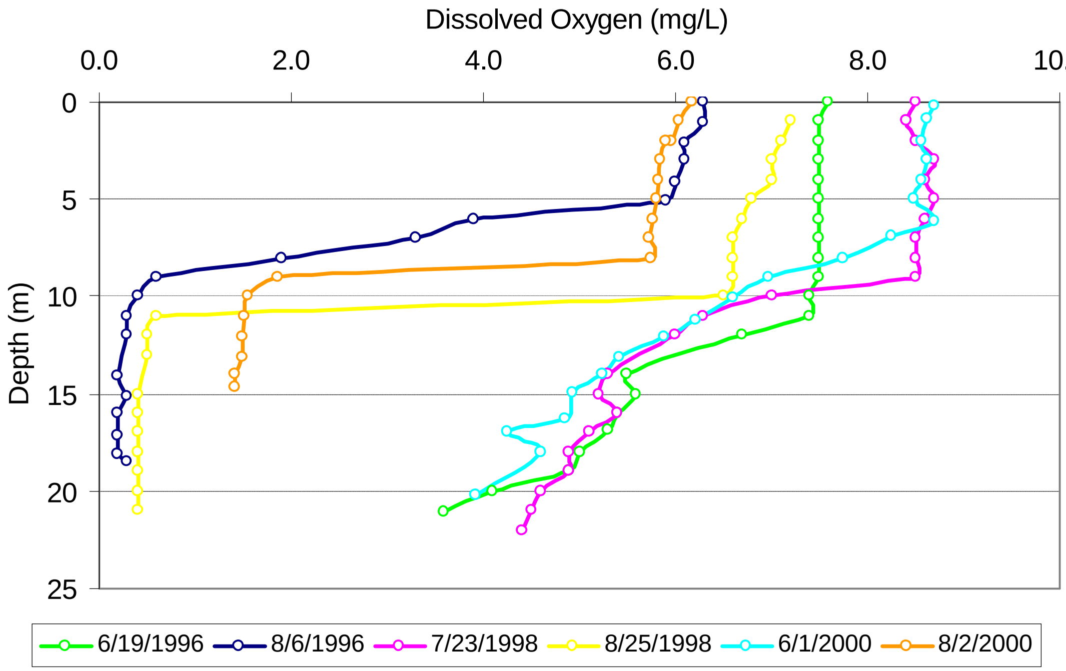

Figure 6. DO conditions at station 492381 (above dam).

2.2 Temperature

Most aquatic organisms are cold-blooded, which means they are unable to internally regulate their core body temperature. Therefore temperature exerts a major influence on their biological activity and growth. Fish, insects, zooplankton, phytoplankton, and other aquatic species all have preferred temperature ranges. As temperatures get too far above or below this preferred range, the number of individuals of the species decreases until finally there are few or none.

The criteria for waters designated as cold water fisheries is 20 °C and the criteria for waters designated as warm water fisheries is 27 °C. When the temperature is below the criteria for at least 90 percent of the water column a fully supporting status is assigned. When the temperature is below the criteria for 75 to 90 percent of the water column a partially supporting status is assigned, and when the temperature is below the criteria for less than 75 percent of the water column a not supporting status is assigned.

Table 7 and Figure 7 display the temperature data for station 492381 in Pineview Reservoir. They indicate that the reservoir is not supporting cold water criteria but is supporting warm water criteria.

Table 7. Observed temperature conditions in Pineview Reservoir (measured at station 492381).

	Cold Water Criteria		Warm Water Criteria	
	Percent of Samples Greater Than 20 EC			
6/19/1996	0	Supporting	0	Supporting
8/06/1996	35	Not Supporting	0	Supporting
7/23/1998	0	Supporting	0	Supporting
8/25/1998	48	Not Supporting	0	Supporting
6/01/2000	0	Supporting	0	Supporting
8/02/2000	71	Not Supporting	0	Supporting

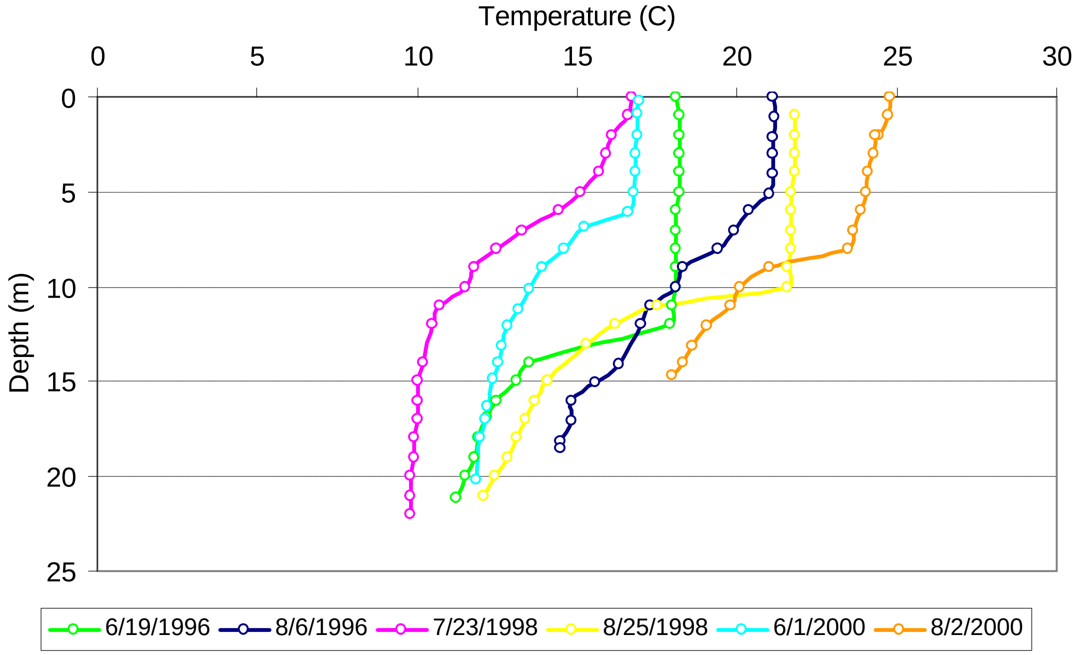

Figure 7. Temperature data for station 492381.

2.3 Total Phosphorus

Under normal conditions, phosphorus is scarce in the aquatic environment. However, human activities have resulted in excessive loading of phosphorus into many freshwater systems, which results in an imbalance of the natural cycling processes. Excess available phosphorus in freshwater systems can result in accelerated plant growth if other nutrients and other potentially limiting factors are available.

The TP target for Utah lakes and reservoirs is 0.025 mg/L. This is not a strict water quality standard but an indicator value and is utilized with the understanding that the ability of a waterbody to assimilate nutrients varies based on factors associated with each waterbody. The average TP concentrations at Pineview Reservoir above the dam are shown in Table 8. The data indicate that the TP target was exceeded on August 6, 1996, August 25, 1998, and August 2, 2000.

The phosphorus to nitrogen ratio is Pineview Reservoir is approximately 20. Ratios above 5 to 10 generally indicate that phosphorus rather than nitrogen limits algal growth (Chapra, 1997).

Table 8. Observed TP conditions in Pineview Reservoir (measured at station 492381).

Date	TP Average (mg/L)	Use Support
6/19/1996	0.0100	Supporting
8/06/1996	0.0383	Not Supporting
6/23/1998	0.0247	Supporting
8/25/1998	0.0380	Not Supporting
6/1/2000	0.0210	Supporting
8/2/2000	0.0470	Not Supporting

2.4 Trophic State Indexes

A frequently used index to assess eutrophication in lakes and reservoirs is that developed by Carlson (1977). Carlson's trophic status index (TSI) uses Secchi depth (SD), chlorophyll *a* (Chl), and TP, each producing an independent measure of trophic state. Index values range from approximately 0 (ultraoligotrophic) to 100 (hypereutrophic). The index is scaled so that TSI = 0 represents a Secchi transparency of 64 meters. Each halving of transparency represents an increase of 10 TSI units. For example, a TSI of 50 represents a transparency of 2 meters (Olem and Flock, 1990). A TSI is calculated from Secchi depth, chlorophyll concentration, and phosphorus concentration (Carlson, 1977; Carlson and Simpson, 1996). The TSI based on chlorophyll concentration is generally believed to be the best indication of eutrophication. The equations for calculating TSI for each of the three parameters are shown below:

$$\text{TSI (Chlorophyll } a) = 30.6 + 9.81 \ln (\text{Chlorophyll } a)$$
$$\text{TSI (TP)} = 4.15 + 14.42 \ln (\text{TP})$$
$$\text{TSI (Secchi depth)} = 60 - 14.41 \ln (\text{Secchi depth})$$

The following classification is used to interpret the TSI:

TSI < 40	most oligotrophic lakes
40 < TSI < 50	mesotrophic lakes
TSI > 50	eutrophic lakes
TSI > 70	hypertrophic lakes

The TSI values for Pineview Reservoir for 1996 to 2000 are shown in Table 9 below. They indicate mesotrophic to eutrophic conditions.

Table 9. Trophic status index scores for Pineview Reservior, 1996 to 2000.

Chlorophyll *a*	43.03	46.09	27.10	38.74
Phosphorus	50.81	54.25	55.00	53.35
Secchi depth	41.95	48.64	39.22	43.25

Algal biomass in Pineview Reservoir were extensively studied during the Clean Lakes study (WBWQMC, 1990). The data indicate that algal biomass in Pineview Reservoir increases with seasonal nutrient availability. The high values in May and early June are associated with spring runoff. The increase in August and continuing into early Fall is primarily associated with the premature overturn of the reservoir caused by the seasonal release of water for irrigation purposes. The early overturn of the lake results in release of nutrients from the hypolimnion to the photic zone.

Thirty-three taxa were encountered during the Clean Lakes study (Table 10). A summary of algal biomass sampled in 2000 is shown in Table 11. Species include eutrophic indicators such as *Anabaena, Aphanizomenon, Ceratium, Chlorella, Euglena*, and *Scenedesmus*. Species representative of oligotrophic conditions were also observed (*Dinobryon, Eunotia, Fragilaria, and Mallomaonas*).

The major groups contributing to algal biomass in Pineview Reservoir are the diatoms and an assortment of green algae. These represented a mix of both eutrophic and oligotrophic indicator species, likely signifying that the reservoir is essentially mesotrophic.

Seasonally the diatoms are most abundant in the winter and spring. The flora in winter was dominated by *Stephanodiscus* with subdominance of *Euglenoid Trachelomanas, Cryptomonas, Scenedesmus*, and *Pediastrum*. During the late summer and fall, *Aphanizomenon* was the dominant species. The dominance of this species seems to be related to the turnover of the lake in August due to drawdown.

Table 10. Pineview Reservoir Phytoplankton sampled during the Clean Lakes Study, 1988.

Blue-Green Algae (Cyanophyta)	Green and Yellow-Green Algae (Chylorophyta)	Diatoms	Flagellates
Anabaena	*Ankistrodesmus*	*Asterionella*	*Ceratium*
Aphanizomenon	*Chlorella*	*Cyclotella*	*Chlamydomonas*
Coccochloris	*Gleocystis*	*Fragilaria*	*Cryptomas*
Oscillatoria	*Oocystis*	*Melosira*	*Dinobryon*
Spirulina	*Pediastrum*	*Meridion*	*Euglena*
	Scenedesmus	*Navicula*	*Geenadinuim*
	Tribonema	*Pinnulavia*	*Mallomonas*
	Tetraedron	*Stephenodiscus*	*Pandorina*
		Surirella	*Phacotos*
		Synedra	*Trachelomonas*

Table 11. Algal taxa present in a total plankton sample collected from the Pineview Reservoir, 492381, August 2, 2000. The percent relative density based on cell volume, species rank in the sample, and the number of organisms and cell volume per milliliter are also provided.

Taxon	Rank	Relative Density	Number Per Milliliter	Cell Volume (m^3/ml)
Bacillariophyta				
Fragilaria Crotonensis	1	58.9	37.6	1,547,472
Pennate Diatoms	10	0.1	3.1	2,504
Stephanodiscus Niagarae	2	19.1	15.7	500,800
Total Bacillariophyta		**78.1**	**56.3**	**2,050,776**
Chlorophyata				
Anabaena Spiroides Var. *Crassa*	3	7.3	3.1	191,706
Crucioenia Species	11	0.1	3.1	2,191
Oocystis Gigas	7	0.7	3.1	18,780
Oocystis Species	8	0.4	6.3	9,390
Pteromonas Species	12	0.1	3.1	1,440
Unknown Spherical Chlorophyta	8	0.4	9.4	9,390
Total Chlorophyta		**8.9**	**28.2**	**232,897**
Chrysophyta				
Chrysocapsa Planktonica	4	6.4	6.3	167,668
Dinobryon Divergens	6	1.3	15.7	34,430
Total Chrysophyta		**7.7**	**21.9**	**202,098**
Cyanophyta				
Microcystis Incerta	5	5.4	9.4	140,850
Total Cyanophyta		5.4	9.4	140,850
Total For All Groups		**100**	**116**	**2,626,621**

3.0 WATER QUALITY TARGETS/ENDPOINTS

The TMDL endpoint or target is the value measured to judge the success of the TMDL effort. In some cases the TMDL endpoint is already specified by the numeric water quality standards that apply to the waterbody. In other cases site-specific TMDL endpoints are required.

3.1 DO

In accordance with Utah's water quality standards and the DEQ's use support guidelines, the endpoint for the Pineview Reservoir TMDL is to have DO concentrations above 4.0 mg/L for at least 50 percent of the water column. The endpoint will be applied at the monitoring station above Pineview Dam (station 492381).

3.2 Temperature

The endpoint for the temperature TMDL using a Class 3A cold water fishery standard is to have average temperatures below the 20 °C criteria for at least 90 percent of the water column. The endpoint for temperature using a Class B warm water fishery standard is 27 °C centigrade in at least 90 percent of the water column. The endpoint will be applied at the monitoring station above Pineview Dam (station 492381).

3.3 Phosphorus

An annual average in-lake dissolved phosphorus target of 0.05 mg/L above the dam was derived for this TMDL based on modeling analysis. This value represents the maximum level for phosphorus that still allows the reservoir to meet the DO and algae targets (see Section 6). However, as discussed in section 6.4, practical experience with other Utah reservoirs and uncertainty from the modeling, indicates that a dissolved phosphorus endpoint of 0.05 mg/L is not protective. Further, existing data meets the 0.05 mg/L level yet nutrient impairment exists. Accordingly, the phosphorus endpoint for this TMDL will be 0.025 mg/L total phosphorus.

3.4 Algae

One of the major concerns of valley residents is the impact of algal blooms within Pineview Reservoir, which typically occur in the late summer months. Algae blooms are a concern because of their impact on recreational uses as well as their potential impact on the drinking water supply. A target of this TMDL will be to shift algal dominance away from blue-green algae, which are the most undesired form of algae because of their aesthetic nuisance and potential to impact drinking water supplies.

4.0 SIGNIFICANT SOURCES

This section identifies all the pollutant sources that contribute to the impairment or threat being addressed by the TMDL. Nutrients, both nitrogen and phosphorus, are the focus because of their impact on algal growths within the reservoir. As nutrient concentrations increase algal growths are stimulated beyond desired levels.

There are no known point source pollution discharges in the watershed. No Utah Pollutant Discharge Elimination System (UPDES) permits have been issued for facilities discharging to Pineview Reservoir or any of its tributaries. Therefore, this report will focus on nonpoint sources of concern.

Various potential sources of nonpoint pollution exist within the Pineview Reservoir watershed. These include nutrient loadings from groundwater, onsite wastewater treatment systems, animal wastes, and tributaries draining to the reservoir. Internal loading from within the reservoir is also a potential source of phosphorus. The tributary loadings are related to the land use activities that occur in the watershed and include agricultural, residential, and, to a smaller degree, commercial activities. Estimated loadings from each of these sources are provided below, including a description of the methodology used to estimate the loadings. Potential future loadings from each source are also estimated.

4.1 Groundwater

4.1.1 Significance and Responsible Parties

A previous study of Pineview Reservoir (WBWQMC, 1990) concluded that contamination of the shallow groundwater aquifer poses the greatest threat to water quality. This is partly due to the fact that the shallow groundwater aquifer discharges most of its water to the reservoir during the summer period when recharge from tributaries is minimal because of irrigation diversions.

Groundwater contamination from nutrients can occur from various sources, including onsite wastewater treatment systems, fertilizer application, animal waste, waste-lagoon sludge, and soil mineralization (USEPA, 1999). The impacts of onsite wastewater treatment systems and animal waste are discussed separately in sections 4.2 and 4.4 below.

Individual homeowners are responsible for loadings from onsite wastewater treatment systems and various landowners are responsible for activities that can pollute the aquifer (e.g., fertilizer application, animal waste, waste-lagoon sludge). In addition, a certain portion of groundwater loadings are natural and cannot be controlled.

Groundwater in Ogden Valley occurs in perched, confined (artesian), and unconfined (water table) aquifers in the valley fill to depths of 600 feet. Each of these is discussed separately below. The information presented below is based primarily on that reported by the Weber Basin Water Quality Management Council (WBWMC, 1988).

4.1.1.1 Confined aquifer

The confined aquifer underlies the western portion of Ogden Valley. The confining layer is as much as 100 feet thick in the lower portion of Ogden Valley. Prior to the construction of Pineview Reservoir, approximately 25 feet of this unit had been exposed near the head of Ogden Canyon due to stream erosion; this probably allowed some discharge from the confined aquifer. It is unlikely that significant discharge presently occurs because Pineview Dam has steel sheet piles that extend to bedrock and block the interval (Doyuran, 1972).

4.1.1.2 Unconfined aquifer beyond the limits of the confining bed

Beyond the limits of the confining bed, unconfined conditions exist in the valley fill. The unconfined aquifer may be several hundred feet thick in some areas near the margins of the confining bed, thinning toward the mountain fronts. The water table is generally 1 to 2 feet below the ground surface at the outer margin of the confining bed in central Ogden Valley and increases in depth toward the valley margins. The depth to the water table fluctuates seasonally by as much as 30 feet. The direction of groundwater movement in the unconfined aquifer is toward the head of Ogden Canyon. Recharge is primarily from streams entering Ogden Valley, irrigation canals, irrigation water applied to the land surface, and direct precipitation.

4.1.1.3 Unconfined aquifer above the confining bed

An unconfined aquifer also exists above the upper confining bed in a relatively thin sequence (10 to 60 feet). The direction of groundwater flow is generally toward Pineview Reservoir where water from the shallow unconfined aquifer ultimately discharges. The slope of the water table is approximately parallel to the land surface. During the irrigation season, groundwater exiting the near-shore sands and gravels along the shore of Pineview Reservoir causes landslides along the bluff above the reservoir exposed by seasonal water level declines. Recharge to the shallow aquifer above the confining bed is primarily from the unconfined aquifer beyond the margin of the confining bed, streamflow, and precipitation falling on the land surface above the confining bed. Discharge is primarily to Pineview Reservoir where the water is either eventually released downstream or evaporated from the reservoir.

Contamination of the shallow groundwater aquifer surrounding the reservoir appears to pose the greatest threat to water quality (WBWQMC, 1990). The Weber Basin Water Quality Management Council (1990) estimated that in 1988 the shallow groundwater aquifer contributed more than 20,000 acre-feet of water to the reservoir during the summer high use period. Since 1988 was a drought year it can be expected that groundwater recharge is greater than this value during normal rainfall years.

4.1.2 Methodology for Estimating Groundwater Loadings

Groundwater nutrient loadings to Pineview Reservoir were estimated using the Generalized Watershed Loading Functions (GWLF) model (Haith et al., 1992). The complexity of GWLF falls between that of detailed, process-based simulation models and simple export coefficient models that do not represent temporal variability. GWLF provides a mechanistic but simplified simulation of precipitation-driven runoff and infiltration. Groundwater seepage is used to estimate dissolved phase pollutant delivery based on groundwater pollutant concentrations.

GWLF simulates runoff and streamflow by a water balance method, based on measurements of daily precipitation and average temperature. Precipitation is partitioned into direct runoff and infiltration using a form of the Natural Resources Conservation Service's (NRCS) curve number method (SCS, 1986). The curve number determines the amount of precipitation that runs off directly, adjusted for antecedent soil moisture based on total precipitation in the preceding 5 days. A separate curve number is specified for each land use by hydrologic soil grouping. Infiltrated water is first assigned to unsaturated zone storage where it may be lost through evapotranspiration. When storage in the unsaturated zone exceeds soil water capacity, the excess percolates to the shallow saturated zone. This zone is treated as a linear reservoir that discharges to the stream or loses moisture to deep seepage, at a rate described by the product of the zone's moisture storage and a constant rate coefficient.

The amount of water available to the shallow groundwater zone is strongly affected by evapotranspiration, which GWLF estimates from available moisture in the unsaturated zone, potential evapotranspiration, and a cover coefficient. Potential evapotranspiration is estimated from a relationship to mean daily temperature and the number of daylight hours. Mean daily temperatures were based on data from the Huntsville Monastery weather station (WRCC, 2000), and evapotranspiration and daylight hours were based on values available in the GWLF manual for western watersheds at the same latitude as the Pineview Watershed.

The monthly groundwater nutrient load to the stream is based on watershed area, nutrient concentration in the groundwater (in milligrams per liter, mg/L), and groundwater discharge to the stream. For the Pineview Reservoir watershed, the area contributing groundwater loadings to the reservoir was based on a best estimate of the size of the unconfined aquifer above the confining bed. Background nutrient concentrations used were 0.75 mg/L dissolved nitrogen and 0.02 mg/L dissolved phosphorus. The nitrogen value is reported by Lowe and Wallace (1997), as cited by the Pineview Basin Water Quality Committee (PBWQC, n.d.) and the phosphorus value is based on observed sampling data. Groundwater loadings predicted by the model during the irrigation months (April to October) were modified to reflect the fact that irrigation diversions contribute groundwater return flows not associated with precipitation. The volume of groundwater (20,000 acre-feet) reported by the Weber Basin Water Quality Management Council (WBWQMC, 1990) was used to estimate nutrient loadings during the summer months.

4.1.3 Estimated Groundwater Loadings

The GWLF model was run for the 1991 to 2001 time period and indicates annual average nitrogen loadings of 21,998 kg and annual average phosphorus loadings of 587 kg. Table 12 provides the average monthly loadings and indicates that the loadings are fairly steady throughout the year. (The summer groundwater loadings would be much less except for the irrigation return flows).

Table 12. Average seasonal nitrogen and phosphorus groundwater loadings to Pineview Reservoir (1991 to 2001). [1]

Month	Dissolved Nitrogen (kg)	Dissolved Phosphorus (kg)
January	1,839	49
February	1,263	34
March	1,514	40
April	1,939	52
May	2,423	65
June	2,714	72
July	2,908	78
August	1,939	52
September	1,939	52
October	1,260	34
November	683	18
December	1,578	42
Annual	**21,998**	**587**

[1] These numbers increased from earlier reports due to the increase in summer loadings associated with irrigation return flows.

4.1.4 Potential Future Groundwater Loadings

Future changes in irrigation practices could potentially have an impact on groundwater nutrient loadings. The conversion of irrigation water from flood irrigation to pressurized irrigation systems would be expected to reduce nutrient loadings to the shallow groundwater aquifer and to the reservoir by reducing the amount of water currently being applied to the agricultural pasture lands.

4.2 Onsite Wastewater Treatment Systems

4.2.1 Significance and Responsible Parties

The extent to which septic and lagoon systems (collectively referred to as onsite wastewater treatment systems) are contributing nutrient loadings to Pineview Reservoir is not known with any certainty. The Pineview Basin Water Quality Committee estimated that there were 2,600 dwellings located in Ogden Valley in 1995 and about 2,300 of these units used onsite waste disposal systems (PBWQC, n.d.). The Weber-Morgan Health Department is responsible for permitting new onsite wastewater disposal systems.

A variety of rules govern the installation of new septic systems. For example, soil characteristics and percolation rates must lie within the range of acceptability for a depth of 4 feet below the absorption field as given in State Rule R317-4, "Soil and Groundwater Requirements." State Rule R317-4 also stipulates that maximum groundwater table levels cannot rise to less than 2 feet below the base of the absorption field.

As mentioned earlier, large return flows from the underlying shallow aquifer to the reservoir are characteristic of the valley. These return flows are the primary source of flow into the reservoir during the summer irrigation season, and are potentially subject to contamination because a relatively large number of onsite wastewater treatment systems are located throughout the valley. Historical 1997 data show that peak nitrate plus nitrite concentrations for the South, Middle, and North Forks of the Ogden River occur in mid- to late-May, coinciding with spring runoff. Concentrations then drastically decrease with the onset of the irrigation season in late May and early June. Nitrate plus nitrite concentrations dramatically increase in the South and North Forks in late June, reflecting the contribution of groundwater return flows to stream systems.

Four types of septic systems are present in the valley: conventional, at-grade, mound, and low-pressure pipe (LPP) systems. (LPP systems are no longer being approved at this time). Most of these systems are conventional septic tank soil-absorption systems. According to the Pineview Water Quality Committee, there were 22 LPP systems, 6 at-grade systems, and 1 mound system operating within the valley in 1998. There are also 3 total containment lagoon systems permitted by DWQ.

4.2.2 Methodology for Estimating Onsite Wastewater Treatment System Loads

Estimating loading from onsite wastewater treatment systems is typically conducted by using a per capita nutrient load estimate and a characterization of the number and location of regional onsite wastewater treatment systems. Additionally, some knowledge of the local soil's ability to retain nitrogen and phosphorus is used to estimate how much of the per capita load reaches surface water sources through groundwater transport. Since no site-specific monitoring information of loading rates from systems in Ogden Valley is available, per capita nutrient loading and soil retention rates were estimated from literature values and the GWLF model. The onsite wastewater treatment system component of GWLF is based on the model developed by Mandel (1993). This is a relatively simple model that estimates nutrient loading using the population served by a system, the per capita daily nutrient load in the effluent, and a rate to account for plant uptake and soil adsorption. For purposes of assessing watershed water quality impacts, onsite wastewater treatment system loads can be divided into four types using the Mandel model: normal systems, short-circuited systems, ponded systems, and direct discharge systems. Each of these types is described in more detail below.

4.2.2.1 Normal systems

A normal onsite wastewater treatment system is a system whose construction and operation conforms to recommended procedures. Effluents from such systems infiltrate into the soil and enter the shallow saturated zone. Effluent nitrogen is converted to nitrate, and except for removal by plant uptake, the nitrogen is transported by groundwater discharge. Conversely, phosphates in the effluent are adsorbed and retained by the soil and hence normal systems provide no phosphorus loads to groundwater. The nitrogen load to groundwater from normal systems is based on per capita daily nutrient load in septic tank effluent (g/day) and per capita daily nutrient uptake by plants in month m (g/day). For this study it was assumed that per capita daily nutrient loads were 24 g/day/capita nitrogen and 4.8 g/day/capita phosphorus. The nitrogen estimate is based on information reported by the Pineview Basin Water Quality Committee (400 gallons per day discharged from a domestic home, 40 mg/L nitrogen concentration in effluent, 2.5 persons per home). The phosphorus estimate is based on an average phosphorus effluent concentration of 7.9 mg/L, which is a literature value (Sedlak, 1991).

Normal systems are generally some distance from streams, and their effluent mixes with other groundwater. Monthly nutrient loads are thus proportional to groundwater discharge to the stream. The portion of the annual load delivered in a particular month is equivalent to the portion of annual groundwater discharge that occurs in that month. No loads of phosphorus are predicted from normal systems because it is assumed that there is complete uptake by plants or soil adsorption.

4.2.2.2 Short-circuited systems

These systems are located close enough to surface waters (less than 15 meters) so that negligible adsorption of phosphorus takes place. The only nutrient removal mechanism is plant uptake.

4.2.2.3 Ponded systems

These systems exhibit hydraulic failure of the tank's absorption field and resulting surfacing of the effluent. Unless the surfaced effluent freezes, ponding systems deliver their nutrient loads to surface waters in the same month that they are generated through overland flow. If the temperature is below freezing, the surfacing effluent is assumed to freeze in a thin layer at the ground surface. The accumulated frozen effluent melts when the snowpack disappears and the temperature is above freezing.

4.2.2.4 Direct discharge systems

These illegal systems discharge effluent directly into surface waters.

4.2.2.5 Lagoon systems

There are three total containment lagoon systems in the valley, serving multiple households. These systems depend on evaporation and a certain amount of discharge to the ground through the bottom of the lagoons. Generally speaking, the minimum liner design for the lagoons will allow a discharge of up to 6,500 gallons per acre per day of partially treated sewage per day through the bottom of the lagoon. The rest of the effluent is disposed of through evaporation. The nutrient loadings from the lagoon systems were estimated separately using the 6,500 gallon per day discharge rate and estimated nutrient concentrations of 40 mg/L dissolved nitrogen and 7.9 mg/L dissolved phosphorus.

4.2.3 Estimated Onsite Wastewater Treatment System Loadings

No data are available regarding the performance of onsite wastewater treatment systems within the Pineview Reservoir watershed (Hazard, 2001). One of the recommendations of this report is to gather sampling data to determine the extent to which these systems are or are not performing adequately.

Because no actual data were available assumptions had to be made concerning the performance of the systems in the valley. On the one hand a national survey of wastewater management officials indicates that Utah has a very low onsite wastewater treatment system failure rate (Nelson et al., 1999). However, site suitability information for Ogden Valley indicates that there are a number of conditions which would be expected to contribute to incomplete treatment of wastewater. These include impermeable soils, steep slopes, shallow groundwater, shallow depth to bedrock, low percolation rates, high percolation rates, and areas subject to flooding (PBWQC, n.d.). Using these two sources of information and best professional judgment, it was assumed that 85 percent of the systems are functioning normally, 10 percent are ponded, and 5 percent are short-circuited. No systems were assumed to be directly discharging to surface waters without treatment (Note that these "failing" systems are a reference to their inability to remove nutrients and bacteria from wastewater. It is not to mean that swage is backing up into homes).

Loadings from onsite wastewater treatment systems were estimated for the 1991 to 2001 time period using the 1995 watershed population of 4,837 (Festin, 2002). Note that this population estimate from the Wasatch Front Regional Council is considerably less than the previous estimate of 6,122 made by the Pineview Basin Water Quality Committee. The 1995 population was used to most closely match the period of the reservoir modeling (see below). Ninety percent of the population was assumed to use septic tanks for onsite wastewater treatment and the remaining ten percent was assumed to use total containment lagoon systems (PBWQC, n.d.). Table 13 shows the estimated nitrogen and phosphorus loadings from onsite wastewater treatment systems for each of the three scenarios.

Table 13. Average monthly nitrogen and phosphorus loading from onsite wastewater treatment systems (1991 to 2001).[1]

Month	Dissolved Nitrogen (kg)	Dissolved Phosphorus (kg)
January	7,674	155
February	6,055	106
March	7,208	107
April	4,508	97
May	1,454	99
June	645	99
July	514	97
August	463	90
September	506	99
October	1,255	81
November	2,621	78
December	6,404	107
Annual	**39,306**	**1,215**

[1] These values have changed slightly from earlier reports due to comments received from reviewers. Loadings from the treatment lagoons were added and the estimate of the valley population was reduced.

4.2.4 Potential Future Onsite Wastewater Treatment System Loadings

Table 14 indicates that the Pineview Reservoir watershed has experienced rapid growth during the past 40 years and all indications are that this growth will continue into the future. To estimate future nutrient loadings from onsite wastewater treatment systems population growth estimates were used to rerun the model. All of the assumptions summarized above regarding discharge volume, nutrient concentrations, and the proportion of failing systems remained the same. The model was run for 2010 and 2020 population estimates, and Table 15 summarizes the results. Both nitrogen and phosphorus loadings are expected to increase significantly.

Table 14. Historic and projected population data for the Pineview Reservoir watershed[1].

Year	Watershed Population	Percent Increase
1960[1]	1,536	–
1970[1]	1,960	27.6
1980[1]	3,241	65.4
1990[2]	4,165	28.5
1995[2]	4,837	16.1
2000[2]	6,622	36.9
2010[2]	7,561	14.2
2020[2]	8,500	12.4

[1] Population estimates for 1960 to 1980 provided by Pineview Basin Water Quality Committee (n.d.).

[2] Population estimates for 1990 to 2020 provided by Wasatch Regional Front (Festin, 2002). Previous population estimates for these years had been based on the Pineview Basin Water Quality Committee and an average growth rate of 20 percent per decade.

Table 15. Estimated future nutrient loadings from onsite wastewater treatment systems.

Year	Dissolved Nitrogen (kg/yr)	Dissolved Phosphorus (kg/yr)
2010	61,340	1,870
2020	68,810	2,090

4.3 Tributary Nonpoint Source Loadings

4.3.1 Significance and Responsible Parties

Tributary streams can deliver large amounts of sediment and associated pollutants to receiving waterbodies both seasonally and annually. Therefore, when considering the total loading of pollutants to Pineview Reservoir these potential contributions must be considered. Computer simulation of rainfall and runoff provides a very useful methodology to examine tributary pollutant contributions. This section outlines the watershed modeling methodology used in this study, and provides a discussion of the modeling results.

The parties responsible for nonpoint source tributary loadings are primarily the landowners from whose lands the pollutants are generated. Land ownership in the watershed consists of U.S. Forest Service, state, and privately owned lands.

4.3.2 Methodology for Estimating Tributary Nonpoint Source Loadings

4.3.2.1 Overview of the SWAT model

Nonpoint source loadings by stream flow to the Pineview Reservoir were estimated using the Soil and Water Assessment Tool (SWAT), version 2000 (Neitsch et al., 2001). The SWAT model was developed to predict the impact of land management practices, such as vegetative changes, reservoir management, groundwater withdrawals, and water transfer, on water, sediment, and agricultural chemical yields in large complex watersheds with varying soils, land use, and management conditions over long periods of time. The model uses a daily time step, and can perform continuous simulation for a 1- to 100-year period. SWAT simulates hydrology, pesticide and nutrient cycling, erosion, and sediment transport. The model was developed by modifying the Simulator for Water Resources in Rural Basins (SWRRB) (Arnold et al., 1990) and the Routing Outputs to Outlet (ROTO) (Arnold, 1990) models for application to large, complex rural basins. SWRRB is a distributed version of the field-scale CREAMS model, and SWAT is an extended and improved version of SWRRB.

4.3.2.2 Description of the ArcView-SWAT interface

An ArcView interface for SWAT (DiLuzio et al., 2001) was employed to efficiently derive and build the input files for SWAT modeling in the Pineview Reservoir watershed. The interface requires digital elevation data (DEMs), land use/land cover, soils, and meteorological data. Digital elevation data representing 7.5-minute U.S. Geological Survey (USGS) quadrangles were downloaded from GEOCommunity (www.geocomm.com), the current distribution center for USGS DEM data.

After computing watershed topographic parameters, the interface uses land cover and soils data in an overlay process to assign soil parameters and SCS curve numbers. The land cover for the watershed area was extracted from the MRLC (MRLC, 1992) database for the state of Utah. Soils information was extracted from the STATSGO soils database (USDA, 1994) for the state of Utah.

The user may decide whether or not to use multiple hydrologic response units (HRUs) in the modeling application. An HRU consists of a unique combination of land use/land cover and soil characteristics, and thus represents areas of similar hydrologic response. If multiple HRUs are not employed, the interface will use the dominant land use and soil characteristic for the entire watershed. To model multiple HRUs, the user must determine a threshold level used to eliminate minor land uses in each subbasin. Land uses that cover a percentage of the subbasin area less than the threshold level are eliminated and the area of the land uses is reapportioned so that 100 percent of the land area in the subbasin is included in the simulation. The ArcView SWAT interface user's manual suggests that a 20 percent land use threshold and a 10 percent soil threshold are adequate for most modeling applications. For the Pineview Reservoir watershed, a 2 percent land use threshold and a 5 percent soil threshold were employed. These threshold values resulted in a highly detailed land use and soil SWAT database, containing many HRUs, which in turn represents a very heterogeneous watershed.

Figure 8 shows the subbasins delineated by the SWAT interface and subsequently used in this study. Table 16 lists the respective land use and area characteristics of each of these subbasins.

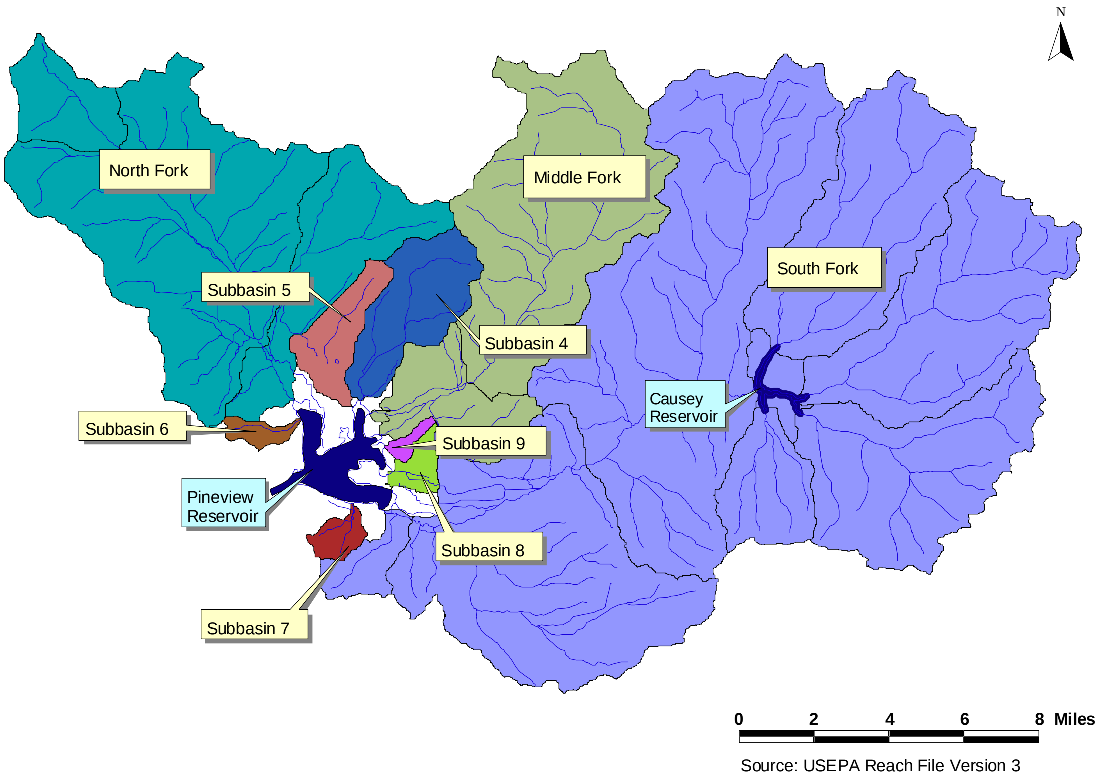

Figure 8. SWAT modeling subbasins.

Table 16. Subbasin land use and area characteristics.

NORTH FORK			
SWAT Land Use	**MRLC Land Use**	**Area (ha)**	**Subbasin Percentage**
Deciduous forest	Deciduous forest	1,047.9	6.8
Evergreen forest	Evergreen forest	1,013.1	6.6
Pasture	Pasture/hay	452.5	2.9
Rangeland–brush	Shrubland	7,854.4	51.2
Rangeland–grasses	Grassland	4,138.2	27.0
Alfalfa	Small grain	790.1	5.1
Forested wetlands	Woody wetlands	46.6	0.3
	Total Subbasin Area	15,342.8	100.0
MIDDLE FORK			
SWAT Land Use	**MRLC Land Use**	**Area (ha)**	**Subbasin Percentage**
Deciduous forest	Deciduous forest	788.4	7.6
Evergreen forest	Evergreen forest	453	4.4
Pasture	Pasture/hay	76.1	0.7
Rangeland–brush	Shrubland	5,728.6	55.5
Rangeland–grasses	Grassland	2,961.7	28.7
Alfalfa	Small grain	126.2	1.2
Forested wetlands	Woody wetlands	189.8	1.8
	Total Subbasin Area	10,323.8	100.0
SOUTH FORK			
SWAT Land Use	**MRLC Land Use**	**Area (ha)**	**Subbasin Percentage**
Deciduous Forest	Deciduous forest	5,518.8	12.1
Evergreen Forest	Evergreen forest	3,157.3	6.9
Rangeland–brush	Shrubland	26,590.4	58.2
Rangeland–grasses	Grassland	10,338.0	22.6
Alfalfa	Small grain	66.0	0.1
	Total Subbasin Area	45,670.5	100.0
SUBBASIN 4			
SWAT Land Use	**MRLC Land Use**	**Area (ha)**	**Subbasin Percentage**
Deciduous forest	Deciduous forest	106.6	4.9
Evergreen forest	Evergreen forest	61.0	2.8
Rangeland–brush	Shrubland	1,370.0	62.4
Rangeland–grasses	Grassland	573.1	26.1
Alfalfa	Small grain	83.5	3.8
	Total Subbasin Area	2,194.2	100.0

Table 16. (continued).

SWAT Land Use	MRLC Land Use	Area (ha)	Subbasin Percentage
SUBBASIN 5			
SWAT Land Use	**MRLC Land Use**	**Area (ha)**	**Subbasin Percentage**
Pasture	Pasture/hay	78.3	7.0
Rangeland–brush	Shrubland	612.4	54.6
Rangeland–grasses	Grassland	191.7	17.1
Alfalfa	Small grain	238.6	21.3
	Total Subbasin Area	1,121.0	100.0
SUBBASIN 6			
SWAT Land Use	**MRLC Land Use**	**Area (ha)**	**Subbasin Percentage**
Deciduous forest	Deciduous forest	25.3	9.4
Rangeland–brush	Shrubland	165.9	61.4
Rangeland–grasses	Grassland	68.0	25.2
Alfalfa	Small grain	10.8	4.0
	Total Subbasin Area	270.0	100.0
SUBBASIN 7			
SWAT Land Use	**MRLC Land Use**	**Area (ha)**	**Subbasin Percentage**
Deciduous forest	Deciduous forest	9.9	2.8
Rangeland–brush	Shrubland	310.4	88.4
Rangeland–grasses	Grassland	19.3	5.5
Alfalfa	Small grain	11.7	3.3
	Total Subbasin Area	351.3	100.0
SUBBASIN 8			
SWAT Land Use	**MRLC Land Use**	**Area (ha)**	**Subbasin Percentage**
Pasture	Pasture/hay	80.9	21.9
Rangeland–brush	Shrubland	35.9	9.7
Rangeland–grasses	Grassland	26.7	7.2
Alfalfa	Small grain	225.1	61.1
	Total Subbasin Area	368.6	100.0
SUBBASIN 9			
SWAT Land Use	**MRLC Land Use**	**Area (ha)**	**Subbasin Percentage**
Row crop	Row crop	4.7	3.2
Evergreen forest	Evergreen forest	1.8	1.2
Pasture	Pasture/hay	38.3	25.9
Rangeland–brush	Shrubland	17.2	11.6
Rangeland–grasses	Grassland	8.4	5.7
Alfalfa	Small grain	77.3	52.3
	Total Subbasin Area	147.7	100

ha=hectars

Figure 8 and Table 16 show that the South Fork subbasin is the largest subbasin in the Pineview Reservoir watershed, draining 45,671 hectares and representing 60 percent of the total watershed area. The North Fork and Middle Fork subbasins drain 15,343 hectares and 10,324 hectares, respectively, and account for approximately 20 percent and 13.6 percent of total watershed area, respectively. Combined, the watersheds of the South, North, and Middle Forks represent approximately 94 percent of the Pineview Reservoir watershed area. The dominant land use types in each of these three major subbasins are shrubland and grassland, representing 88.8 percent of the cover in the South Fork subbasin, 78.2 percent of the cover in the North Fork subbasin, and 84.2 percent of the cover in the Middle Fork subbasin.

4.3.2.3 Meteorological data

SWAT requires daily precipitation, temperature, relative humidity, solar radiation, and wind speed data. These parameters may be given in a site-specific, user-specified file, they may be estimated using a climate simulator, or several may be specified in a file and others simulated. The interface will search and find the station closest to the mean center of each subbasin, and assign that station's meteorological parameters to the subbasin. Daily precipitation and temperature data were obtained from the National Climatic Data Center (NCDC) for the Huntsville Monastery station (station 424135). Daily data are available for this station from November 1976 to May 2001. A search of the NCDC archives and a telephone call to the center revealed that no other meteorological stations with data covering this time period are available for the watershed. Additionally, surrounding National Weather Service sites are located at a greater distance from watershed mean centers than the Huntsville station. Thus, precipitation and temperature recorded at the Huntsville site were used to describe those meteorological parameters for the entire watershed. Relative humidity, solar radiation, and wind speed were simulated using a climate simulator available in SWAT 2000. The climate simulator uses historical data collected from surrounding National Weather Service sites to estimate parameters. It is believed that these stations are quite adequate for estimating relative humidity, solar radiation, and wind speed for the Pineview Reservoir watershed.

4.3.2.4 Model simulation period

SWAT 2000 was run for the Pineview Reservoir watershed from November 1989 through September 2000. The time period of simulation for the CE-QUAL-W2 modeling efforts is from January 1991 through September 2000. The earlier beginning time for the SWAT application allows the model to operate through an annual hydrologic cycle before using the model output for CE-QUAL-W2 input. Each subbasin defined by the ArcView-SWAT interface was modeled individually.

4.3.3 Estimated Tributary Nonpoint Source Loadings

The SWAT model produces (HRU) reports that describe the annual contribution of runoff, sediment, and associated pollutants from individual HRUs to subbasin stream reaches. These HRU data may be used to provide information about the source area contribution to the overall pollutant loading from the watershed.

4.3.3.1 Annual average subbasin pollutant transport to stream reaches

For each subbasin, SWAT produces reports that describe the total annual transport by runoff of sediment and associated pollutants into the subbasin stream reach from unique combinations of land use and soil type. Estimates of dissolved nitrogen, organic phosphorus, sediment phosphorus, and dissolved phosphorus are made.

Table 17 summarizes the pollutant transport according to land cover and land use for each subbasin. A summary of annual average pollutant transport in the watershed is given in Table 18.

Table 17. Subbasin annual pollutant transport (kg) to stream reaches estimated by the SWAT model.[1]

NORTH FORK **Land Use**	**Dissolved Nitrogen**	**Organic Phosphorus**	**Sediment Phosphorus**	**Dissolved Phosphorus**	**TP**
Deciduous forest	1,082	133	18	25	176
Evergreen forest	24	4	1	16	21
Pasture	3,564	434	103	9	545
Rangeland–brush	658	82	25	426	533
Rangeland–grasses	854	107	22	287	416
Alfalfa	65	8	2	38	48
Forested wetlands	21	3	0	1	4
Total	6,266	769	173	802	1,744
MIDDLE FORK **Land Use**	**Dissolved Nitrogen**	**Organic Phosphorus**	**Sediment Phosphorus**	**Dissolved Phosphorus**	**TP**
Deciduous forest	814	100	14	19	132
Evergreen forest	11	2	1	7	10
Pasture	599	73	17	1	92
Rangeland–brush	480	60	18	310	389
Rangeland–grasses	611	76	16	206	298
Alfalfa	10	1	0	6	8
Forested wetlands	84	10	2	5	17
Total	2,610	322	68	555	945
SOUTH FORK **Land Use**	**Dissolved Nitrogen**	**Organic Phosphorus**	**Sediment Phosphorus**	**Dissolved Phosphorus**	**TP**
Deciduous forest	5,022	616	79	128	823
Evergreen forest	3	1	3	44	48
Rangeland–brush	6,193	755	173	1,298	2,226
Rangeland–grasses	5,264	644	155	674	1,473
Alfalfa	5	1	0	3	4
Total	16,488	2,017	411	2,146	4,574
SUBBASIN 4 **Land Use**	**Dissolved Nitrogen**	**Organic Phosphorus**	**Sediment Phosphorus**	**Dissolved Phosphorus**	**TP**
Deciduous forest	22	3	0	3	6
Evergreen forest	0	0	0	1	1
Rangeland–brush	8	2	1	88	91
Rangeland–grasses	5	1	1	41	42
Alfalfa	7	1	0	4	5
Total	43	6	3	137	145
SUBBASIN 5 **Land Use**	**Dissolved Nitrogen**	**Organic Phosphorus**	**Sediment Phosphorus**	**Dissolved Phosphorus**	**TP**
Pasture	819	100	23	2	125
Rangeland–brush	181	23	7	25	54
Rangeland–grasses	35	4	1	13	18
Alfalfa	106	125	78	5	208
Total	1,141	252	110	44	405

Table 17. (continued).

SUBBASIN 6 **Land Use**	**Dissolved Nitrogen**	**Organic Phosphorus**	**Sediment Phosphorus**	**Dissolved Phosphorus**	**TP**
Deciduous forest	2	0	0	0	1
Rangeland–brush	0	0	0	7	7
Rangeland–grasses	0	0	0	4	4
Forested wetlands	1	0	0	0	0
Total	4	1	0	12	13
SUBBASIIN 7 **Land Use**	**Dissolved Nitrogen**	**Organic Phosphorus**	**Sediment Phosphorus**	**Dissolved Phosphorus**	**TP**
Deciduous forest	40	5	1	0	6
Rangeland–brush	60	8	2	15	25
Rangeland–grasses	6	1	0	1	2
Alfalfa	1	0	0	1	1
Total	107	13	4	18	34
SUBBASIN 8 **Land Use**	**Dissolved Nitrogen**	**Organic Phosphorus**	**Sediment Phosphorus**	**Dissolved Phosphorus**	**TP**
Pasture	21	3	1	1	4
Rangeland–brush	0	0	0	0	0
Rangeland–grasses	0	0	0	1	1
Alfalfa	52	7	2	2	10
Total	74	9	3	3	15
SUBBASIN 9 **Land Use**	**Dissolved Nitrogen**	**Organic Phosphorus**	**Sediment Phosphorus**	**Dissolved Phosphorus**	**TP**
Row crop	0	0	0	0	0
Evergreen forest	0	0	0	0	0
Pasture	14	2	0	0	2
Rangeland–brush	0	0	0	0	0
Rangeland–grasses	0	0	0	0	0
Alfalfa	29	4	1	1	5
Total	43	5	1	1	8

[1] Dissolved nitrogen consists of nonparticulate organic nitrogen. Organic phosphorus mainly consists of living plants, animals, and bacteria, as well as organic detritus. Sediment phosphorus consists of phosphate minerals, sorbed orthophosphate (e.g., on clays), and phosphate complexed with solid matter. Dissolved phosphorus is the form that is readily available to plants. Total Phosphorus (TP) consists of organic phosphorus, sediment phosphorus, and dissolved phosphorus.

Table 18. Annual average watershed pollutant transport (kg) to stream reaches summarized by land use.

Land Use	Dissolved Nitrogen	Organic Phosphorus	Sediment Phosphorus	Dissolved Phosphorus	TP
Deciduous forest	6,982	856	113	174	1,144
Evergreen forest	39	6	5	068	8
Pasture	5,017	611	144	13	767
Rangeland–brush	7,580	930	227	2,170	3,327
Rangeland–grasses	6,775	833	195	1,227	2,255
Alfalfa	277	146	84	59	289
Row crop	0	0	0	0	0
Forested wetlands	106	13	2	7	22
Total	**26,776**	**3,395**	**770**	**3,718**	**7,883**

The total amount of pollutants transported from a source to a stream reach is governed by subbasin area. Table 17 shows that the greatest pollutant transport of dissolved nitrogen, organic phosphorus, sediment phosphorus, and dissolved phosphorus into tributary streams occurs in the South Fork subbasin. The South Fork subbasin is by far the greatest contributor of nutrients to its stream reaches in the Pineview Reservoir, simply because of its large size (60 percent of total watershed area). The second and third greatest contributions of nutrients to stream reaches occurs in the North Fork and Middle Fork subbasins, respectively. Interestingly, Subbasin 5, with a much smaller area (1,121 ha), is estimated to transport large amounts of dissolved nitrogen, organic phosphorus, and sediment phosphorus to its stream reach. This is due to the relatively large amount of agricultural area in the subbasin.

The transport of nutrients to stream reaches is much lower in the remaining subbasins. Dissolved nitrogen and dissolved phosphorus transport is somewhat significant in Subbasins 4 and 7, while Subbasins 6, 8, and 9 contribute relatively little to their respective stream reaches.

Table 18 summarizes pollutant transport to stream reaches according to land use for the entire watershed. The table shows that the greatest sources of pollutant transport to stream reaches are from rangeland brushes and grasses, which dominate the Pineview Reservoir watershed. Deciduous forest is seen to contribute significant amounts of all nutrients to stream reaches, while pasture land use contributes large amounts of nitrogen and organic phosphorus.

4.3.3.2 Model calibration

The SWAT model was calibrated by matching its output to the observed loadings data for the South Fork Ogden River. This was the only tributary for which both flow and water quality data are available so it was the only tributary for which annual observed loads could be calculated. The SWAT model was considered to be satisfactory for predicting both phosphorus loads (4,574 kg/yr predicted to 4,553 kg/yr observed) and nitrogen loads (17,607 kg/yr predicted to 19,375 kg/yr observed)[1].

[1] The model output was compared to nitrate loads because this is the form of nitrogen that was sampled.

4.3.3.3 Average monthly subbasin pollutant transport to stream reaches

Table 19 lists the average monthly subbasin pollutant transport to stream reaches estimated by the SWAT model for the Pineview Reservoir watershed. The table shows that the greatest monthly pollutant transport typically occurs in the wetter winter months of December, January, February, and March. The SWAT modeling is predicting earlier loadings than would be expected in a snowmelt-driven watershed such as Pineview Reservoir. This appears to be due to the use of precipitation and temperature data from the Huntsville Monastery station, which is not believed to entirely capture conditions at the upper elevations of the watershed. However, the total annual loads predicted by the model, which are of greatest concern for this study, are still believed to be valid.

Table 19. Monthly average pollutant transport (kg) to stream reaches.

January	1,071	136	31	149	316
February	10,759	1,363	309	1,530	3,202
March	9,256	1,174	267	1,272	2,713
April	0	0	0	0	0
May	0	0	0	0	0
June	1,013	129	29	134	292
July	0	0	0	0	0
August	0	0	0	0	0
September	0	0	0	0	0
October	0	0	0	0	0
November	1,940	247	56	247	550
December	2,735	347	79	386	812
Total	**26,774**	**3,396**	**771**	**3,718**	**7,885**

Table 17 also reflects the dominance of the North, Middle, and South Fork subbasins in terms of pollutant transport capability. Subbasins 4, 5, and 7 also contribute to monthly pollutant transport, while subbasins 6, 8, and 9 are relatively unimportant in the transport of pollutants to their respective stream reaches.

It is important to note that water diversions from the streams of the North Fork, Middle Fork, and South Fork subbasins occur during the irrigation season. These diversions remove all flow from the streams causing the streams to be very dry from April to October. Consequently, there are reduced pollutant loadings to the reservoir from the surface waters of the North Fork, Middle Fork, and South Fork subbasins during these periods. The table shows that the greatest monthly pollutant transport typically occurs in the wetter winter months of December, January, February, and March. The SWAT modeling is predicting earlier loadings than would be expected in a snowmelt-driven watershed such as Pineview Reservoir. This appears to be due to the use of precipitation and temperature data from the Huntsville Monastery station, which is not the same as conditions at the upper elevations of the watershed. However, the total annual loads predicted by the model, which are of greatest concern for this study, should still be valid.

The SWAT model also predicts very little pollutant transport during the dryer summer months, again based on the precipitation data from the Huntsville Monastery. The model suggests that the month of June sees the transport of important volumes of organic nitrogen and organic phosphorus, which is due to several large precipitation events (greater than 1 inch) that have historically occurred during that month.

4.3.4 Potential Future Tributary Nonpoint Source Loadings

Potential impacts of future growth in the Pineview Reservoir watershed on surface water quality were assessed through the use of 1) estimated future population growth in the watershed; 2) assumed type and distribution of growth within the watershed; and 3) application of land-use change scenarios reflecting the population and development assumptions above and subsequently modeled in SWAT. Each of these three components is discussed below.

4.3.4.1 Projected future population growth

Projected future growth for the Pineview Reservoir watershed was based on information provided by the Wasatch Front Regional Council.

4.3.4.2 Assumed character and distribution of growth

Population increases were assumed to be characterized entirely as an increase in low-intensity residential land use. It was assumed that each new detached residential unit would house 2.5 persons. Therefore, a population increase of 939 persons by the year 2010 would result in the addition of 375 residential units within the watershed, and another 375 additional residential units by the year 2020. Furthermore, it was assumed that new residential units would be sited on a minimum lot size of 3 acres. Consequently, approximately 1,125 acres (455 hectares) were converted to low-intensity residential land use in the 2010 scenario, with an additional 1,125 acres converted to low-intensity residential land use in the 2020 scenario.

Shrub and grass rangeland was assumed to be the predominant land cover converted to low density residential land use. Small areas of deciduous and evergreen forest were also converted to residential land use. Agricultural land uses were assumed to retain their current area extents. The distribution of growth was assumed to occur only in the lowermost portions of the North Fork, Middle Fork, and South Fork subbasins, in close proximity to the reservoir. Land use conversion was distributed equally within these three subbasins. Figures 9 and 10 show the locations and spatial extent of the 2010 and 2020 land-use change scenarios, respectively.

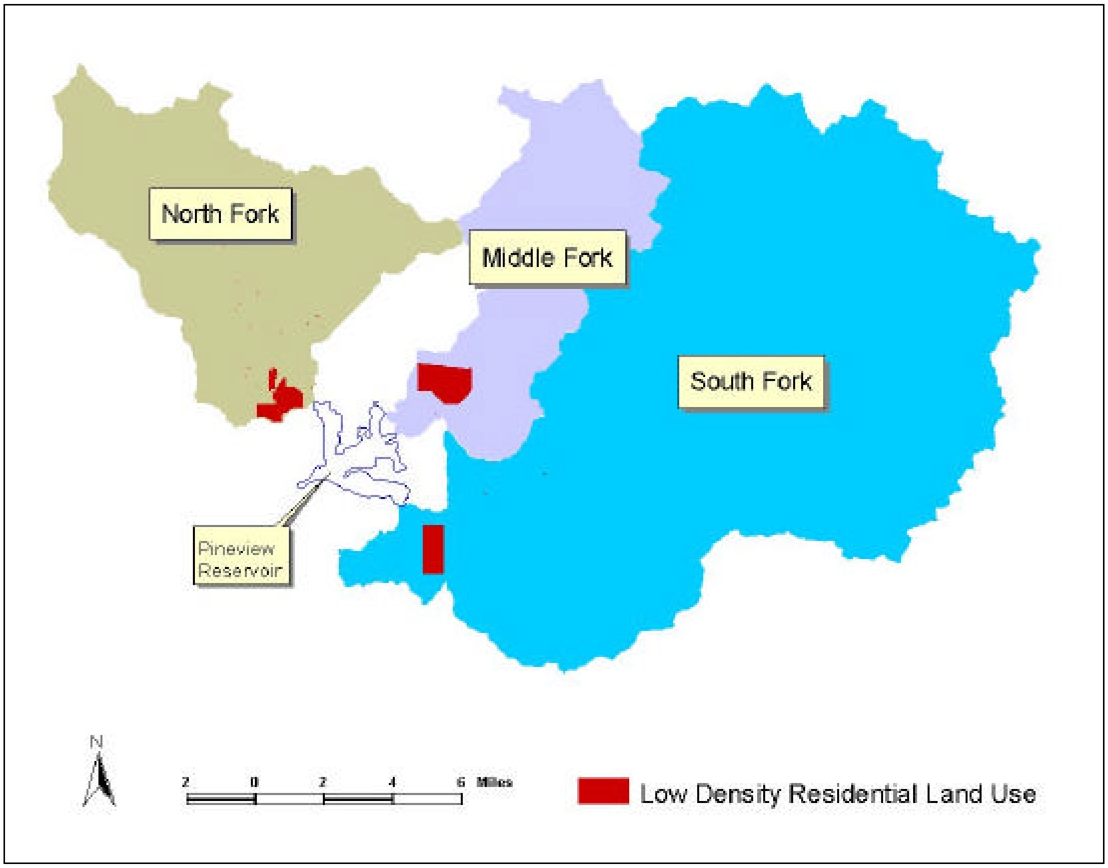

Figure 9. Estimated location and extent of urban development, 2010.

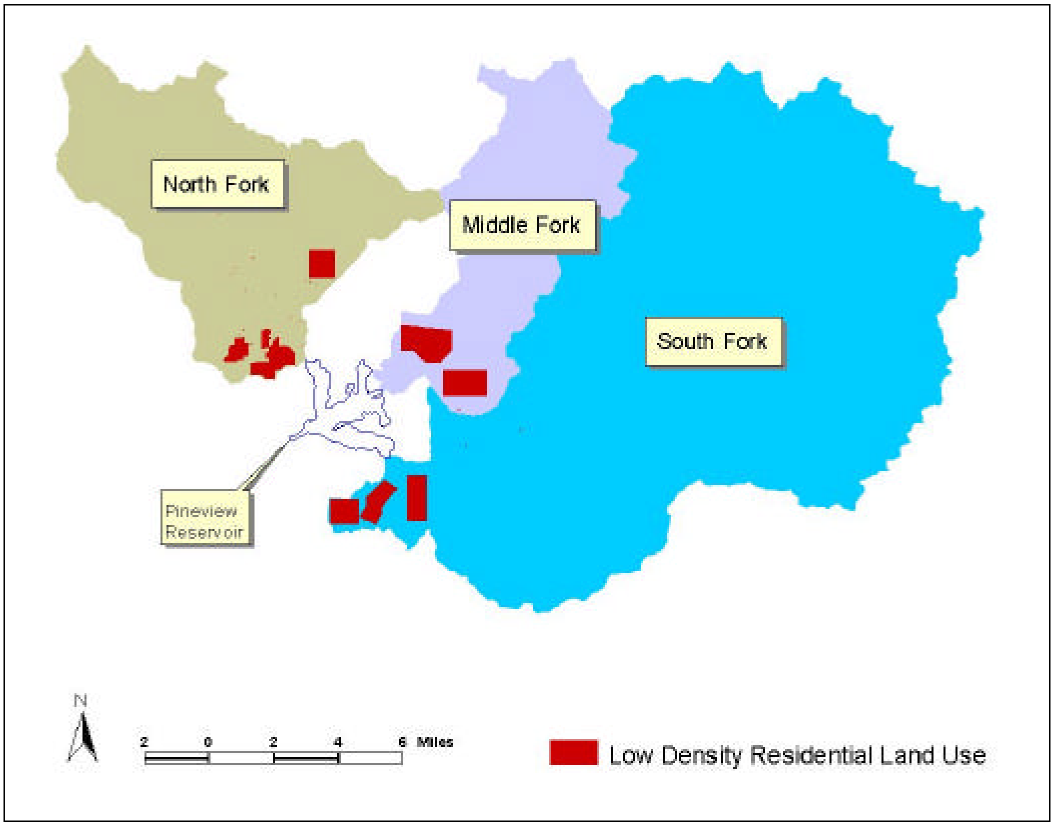

Figure 10. Estimated location and extent of urban development, 2020.

4.3.4.3 Estimated impact of future growth on surface water quality

Surface water quality impacts from potential future suburban growth were examined with the use of the SWAT model. Land-use data were edited according to the development scenarios described above. All other model parameters were held constant to the predevelopment conditions. Table 20a-20c lists the SWAT simulation results for the 2010 scenario, and Table 21a-12c gives the results of the 2020 scenario. These results indicate that there will be negligible impacts to nutrient loading due to the conversion from shrublands to low-density residential lands. Recall that the land-use change scenario called for a change from rangeland shrubs and grasses to low-density residential land use. Changes in land use affect curve numbers and therefore affect runoff potential. For example, the average curve number associated with the rangeland cover type occurring on "B" hydrologic soils is 65, while the curve number associated with low-density residential land-use occurring on "B" hydrologic soils is 59 (Appendix B-9). This means that more precipitation is predicted to infiltrate into low-density residential lands compared to rangeland. The low-density residential land use will, therefore, generate less runoff per unit area even though the concentration of nutrients in the runoff is expected to be higher.

Table 20a. Annual average pollutant transport (kg) to stream reaches from hypothetical suburban development scenario, 2010: North Fork Subbasin.

Land Use	Dissolved Nitrogen	Organic Phosphorus	Sediment Phosphorus	Soluble Phosphorus	TP
Deciduous forest	907	112	15	21	147
Evergreen forest	20	3	1	14	18
Pasture	3,058	372	88	8	468
Rangeland–brush	645	80	25	418	523
Rangeland–grasses	739	93	20	249	360
Alfalfa	56	7	2	33	41
Low density residential	4	1	0	20	21
Forested wetlands	18	3	0	1	3
Total	**5,447**	**671**	**151**	**764**	**1,581**

Table 20b. Annual average pollutant transport (kg) to stream reaches from hypothetical suburban development scenario, 2010: Middle Fork Subbasin.

Land Use	Dissolved Nitrogen	Organic Phosphorus	Sediment Phosphorus	Soluble Phosphorus	TP
Deciduous forest	746	92	13	17	121
Evergreen forest	10	1	1	7	9
Pasture	600	138	34	3	175
Rangeland–brush	467	58	18	301	379
Rangeland–grasses	551	69	15	188	272
Alfalfa	10	1	0	6	8
Low density residential	44	7	2	22	30
Forested wetlands	77	9	1	5	16
Total	**2,505**	**375**	**84**	**549**	**1,010**

Table 20c. Annual average pollutant transport (kg) to stream reaches from hypothetical suburban development scenario, 2010: South Fork Subbasin.

Land Use	Dissolved Nitrogen	Organic Phosphorus	Sediment Phosphorus	Soluble Phosphorus	TP
Deciduous forest	4,603	563	73	116	753
Evergreen forest	63	1	3	40	44
Rangeland–brush	6,157	750	172	1,291	2,213
Rangeland–grasses	5,208	632	155	653	1,440
Alfalfa	5	1	0	3	4
Low density residential	83	2	0	60	62
Total	**16,119**	**1,949**	**403**	**2,163**	**4,516**

Table 21a. Annual average pollutant transport (kg) to stream reaches from hypothetical suburban development scenario, 2020: North Fork Subbasin.

Land Use	Dissolved Nitrogen	Organic Phosphorus	Sediment Phosphorus	Soluble Phosphorus	TP
Deciduous forest	1,056	129	18	24	171
Evergreen forest	23	4	1	16	21
Pasture	3,564	434	103	9	545
Rangeland–brush	632	79	24	409	512
Rangeland–grasses	851	106	22	286	415
Alfalfa	65	8	2	38	48
Low density residential	108	6	1	75	80
Forested wetlands	21	3	0	1	4
Total	**6,320**	**769**	**171**	**858**	**1,796**

Table 21b. Annual average pollutant transport (kg) to stream reaches from hypothetical suburban development scenario, 2020: Middle Fork Subbasin.

Land Use	Dissolved Nitrogen	Organic Phosphorus	Sediment Phosphorus	Soluble Phosphorus	TP
Deciduous forest	746	92	13	17	121
Evergreen forest	10	1	1	7	9
Pasture	1,133	138	34	3	175
Rangeland–brush	454	57	17	293	368
Rangeland–grasses	544	68	15	186	269
Alfalfa	10	1	0	6	8
Low density residential	105	16	4	65	85
Forested wetlands	77	9	1	5	16
Total	**3,079**	**382**	**85**	**582**	**1,051**

Table 21c. Annual average pollutant transport (kg) to stream reaches from hypothetical suburban development scenario, 2020: South Fork Subbasin.

Land Use	Dissolved Nitrogen	Organic Phosphorus	Sediment Phosphorus	Soluble Phosphorus	TP
Deciduous forest	4,603	563	73	116	753
Evergreen forest	63	1	3	40	44
Rangeland–brush	6,122	746	171	1,283	2,200
Rangeland–grasses	5,275	640	157	662	1,459
Alfalfa	5	1	0	3	4
Low density residential	49	2	0	44	47
Total	**16,117**	**1,953**	**404**	**2,148**	**4,507**

4.4 Animal Wastes

Nutrient loadings from animal wastes in the Pineview Reservoir watershed are not insignificant. Although good data on the number of animals in the watershed are not available, the Ogden Farm Service Agency estimates that there are approximately 80 dairy cattle, 400 beef cattle, and 500 horses in Ogden Valley (Fowers, 2001). A significant number of sheep are also located in the valley but no population estimates are available.

Nutrient loads from beef and dairy cattle were estimated using loading rates available from the American Society of Agricultural Engineers (ASAE, 1998). Nutrient loads from horses were estimated using loading rates available from the NRCS Agricultural Waste Management Field Handbook (NRCS, 1992). Table 22 summarizes the data. These values were used to obtain loading rates in grams per day, which were then input to the Mandel model to estimate loadings to the reservoir. The Mandel model was used to address the fact that not all nutrients generated by these animals will be delivered to the reservoir because of nutrient uptake by plants and soil adsorption.

Table 22. Estimated nutrient loadings from animal wastes in the Pineview Reservoir watershed.

Type of Animal	Number of Animals	Average Weight of Animal (kg)	Dissolved Nitrogen		Dissolved Phosphorus	
			Rate (kg/1,000 kg animal weight/day)	Estimated Loads (kg/year)	Rate (kg/1,000 kg animal weight/day)	Estimated Loads (kg/year)
Horse	500	450	0.127	10,129	0.023	980
Beef cattle	400	360	0.254	13,052	0.030	820
Dairy cattle	80	640	0.371	6,874	0.061	600
Total	**980**	**--**	**--**	**30,055**	**--**	**2,400**

4.5 Internal Loading

Under certain conditions, bottom sediments can be important sources of phosphorus to the overlying waters of reservoirs, particularly if the reservoir is shallow or has an anaerobic hypolimnium (Chapra, 1997). Phosphorus flux from sediment deposits is strongly affected by sediment composition and oxygen levels in the water column; sediment release can contribute significant nutrient loadings during low-oxygen conditions. Typically, larger lakes and reservoirs are susceptible to low oxygen levels during periods of stratification, which usually occur in middle to late summer. Under low-oxygen conditions, phosphorus may be released from the sediment layer, entering the water column and contributing to loading. Indicators of potential nutrient loading from sediment sources include probable high concentrations of phosphorus in the sediment and known low-oxygen conditions in the waterbody, or evidence of algal blooms following turnover in the late summer or early fall.

Estimates of internal phosphorus loadings were made using the CE-QUAL-W2 reservoir model. Release rates from the sediment were set at 5 $mg/m^2/day$ based on literature values. Internal loadings were assumed to occur only when DO falls below 0.2 mg/L. Because the model predicts very few days with DO below this value, internal phosphorus loadings are negligible.

4.6 Source Summary

Table 23 summarizes the estimates of dissolved nitrogen and dissolved phosphorus loadings by major source category. It indicates that onsite wastewater treatment systems are potentially the largest contributor of nitrogen, whereas tributary loadings are potentially the largest contributor of phosphorus. Dissolved phosphorus is presented because that is the form most readily available to the algae in the reservoir and because it will be the focus of the TMDL. The W2 model is also limited in its ability to simulate the impacts of other forms of phosphorus.

Table 23. Summary of annual nutrient loads in the Pineview Reservoir watershed by major source category.[1]

	Dissolved Nitrogen (kg/yr)	Dissolved Phosphorus (kg/yr)
Groundwater	21,998	587
Onsite wastewater treatment systems	39,306	1,215
Tributary loadings	26,774	3,718
Animal wastes	30,055	2,400
Total	**118,133**	**7,920**

[1] These values have changed from previous reports due to revised population estimates and new nutrient generation rates for horses.

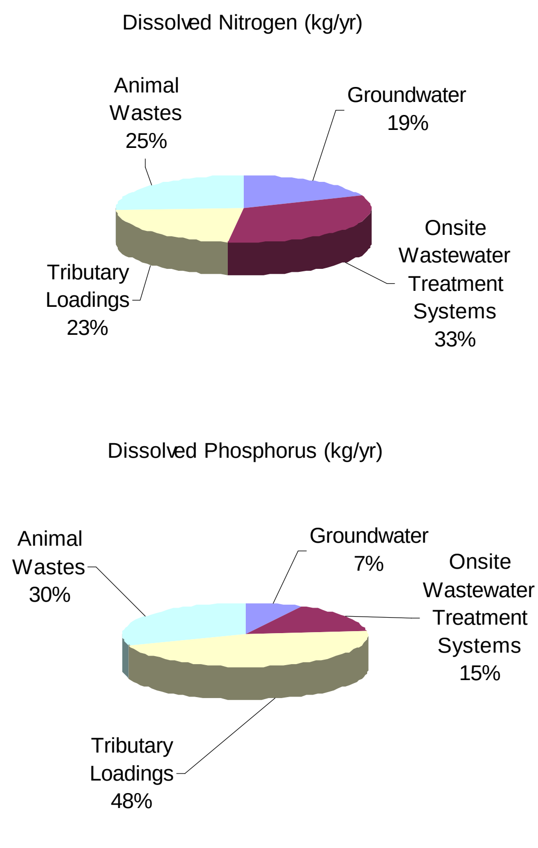

Figure 11. Pineview Reservoir loading summary.

5.0 TECHNICAL ANALYSIS

Establishing the relationship between the in-reservoir water quality targets and source loadings is a critical component of TMDL development. It allows for the evaluation of management options that will achieve the desired outcome in terms of water quality. The link can be established through a range of techniques, from qualitative assumptions based on sound scientific principles to sophisticated modeling techniques. Ideally, the linkage will be supported by monitoring data that allow the TMDL developer to associate certain waterbody responses with flow and loading conditions. The objective of this section is to present the approach taken to develop the linkage between sources and reservoir response for TMDL development in the Pineview Reservoir watershed.

5.1 Modeling Approach and Model Selection

Table 24 lists a number of publicly available lake and reservoir eutrophication models. The first three are steady-state models while the remaining six are time-variable models. The Vollenweider model and its loading plots are primarily a zero-dimensional, steady state analysis of trophic status of the lake. Because of its steady state and completely mixed assumptions, the Vollenweider model lacks the ability to mimic the conditions observed in many lakes and reservoirs and is therefore better suited for use in planning

Table 24. Lake and reservoir eutrophication models.

Modeling Framework	Description	Data Requirements
Vollenweider	Plot of TP vs. average depth	TP loads and average depth
EUTROMOD	Regression model of DO and TP	Climate, watershed, and lake morphometry
BATHTUB	Empirical model calculating DO, nitrogen, phosphorus, and chlorophyll a	Watershed characteristics, water and nutrient loads, and reservoir morphology
PHOSMOD	Time-variable simulations of TP in water column	Stratification periods, initial lake phosphorus, and hypolimnetic DO
Sediment-Water Interaction Model	Time-variable simulations of particulate and dissolved phosphorus in water column and sediment	Similar to that in PHOSMOD plus sediment data
CE-QUAL-W2	2-dimensional, laterally averaged eutrophication model for reservoir	Hydraulic geometry, hydrodynamic, and water quality data
WASP/EUTRO5	3-dimensional eutrophication model for rivers, lakes, and estuaries	Similar to that for CE-QUAL-W2
CE-QUAL-ICM	3-dimensional eutrophication model for rivers, lakes, and estuaries	Similar to that for WASP/EUTRO5
EFDC	3-dimensional hydrodynamic and water quality model	Most comprehensive data needed

purpose. EUTROMOD is a spreadsheet-based watershed and lake modeling procedure and is only appropriate for predictions of growing season average conditions. BATHTUB performs steady-state water and nutrient balance calculations in a spatially segmented hydraulic network, which accounts for advective and diffusive transport, and nutrient sedimentation. It is an empirical model without the quantitative cause-and-effect relationship between loading to and response in the reservoir. PHOSMOD is a total phosphorus budget model of the water column and sediment. This model is not capable of addressing longitudinal variations in a reservoir such as Pineview. The phosphorus model by Lung is a time-variable, 1-dimensional phosphorus model, simulating particulate and dissolved phosphorus concentrations in the water column and sediments. However, it does not include algal biomass and other nutrients such as nitrogen. The USEPA's WASP/EUTRO5 model is probably the most widely used modeling framework in wasteload allocations and TMDLs at the present time. Its main drawback is that it does not have a hydrodynamic model to independently calculate the mass transport in the water column. The CE-QUAL-ICM and EFDC models are both 3-dimensional, thereby requiring a significant amount of data, which are beyond what is available for Pineview Reservoir.

The CE-QUAL-W2 model (called W2) is a 2-dimensional (longitudinal-vertical) hydrodynamic and water quality code specifically designed for reservoirs. As indicated earlier, the three water quality constituents cited for water quality impairment concern are TP, temperature, and DO. W2 is very well suited for Pineview Reservoir, where vertical stratification of temperature and DO during the summer months must be reproduced.

5.2 Data to Support the Modeling Analysis

The W2 model requires a significant amount of site-specific data to configure and calibrate. Initial configuration and hydrodynamic calibration of the Pineview Reservoir model was done by the Bureau of Reclamation and Tetra Tech, Inc. completed the water quality calibration.

Water surface elevations are routinely monitored at the Pineview Reservoir. The elevations recorded during the period from 1991 to 2000 are displayed in Figure 12, showing seasonal fluctuations up to 18 meters throughout the year. The reservoir usually reaches its top capacity in late spring and early summer responding to the significant spring runoff from the watershed. Figure 13 shows the seasonal inflow rates from the South Fork, displaying the spring peak flows during the year except 1992 when the inflows were minimal throughout that year, resulting in the lowest reservoir volume by the end of 1992 (see Figure 12). The data in Figure 13 are developed from USGS gaging station 10137500 in the South Fork and made available by the U.S. Bureau of Reclamation (USBR). Flows from the Middle and North Forks were derived from relationships between the gaging station at the South Fork and the two stations in Middle and North Forks, respectively. The regression relationships were based on the flows measured at these stations from October 1, 1963 to September 30, 1974. As expected, the derived flows from the Middle and North Forks follow the temporal pattern of the flows from the South Fork, but at a lower rate. Data on groundwater inflow to the reservoir are limited. The incorporation of groundwater flows is discussed in the hydrodynamic model calibration section.

It should be pointed out that extensive time-series water quality data are needed to configure and calibrate the W2 water quality simulations. In this case, the receiving water quality data for model calibration is quite limited, particularly the data collected in recent years. Only two sampling events were conducted in 1996, 1998, and 2000, primarily in the summer period. (Note that a reasonable database for this type of W2 model application should consist of field surveys conducted on a biweekly basis.)

Nutrient concentrations in the water column have not been monitored as frequently as is desired for this type of modeling analysis (i.e., only two sampling events in each of the following years: 1992, 1994, 1996, 1998, and 2000). Therefore, water quality data to support the modeling analysis is quite limited. Very limited flow data along with small amounts of water quality data from the tributary stations 492434 (South Arm), 492466 (Middle Arm), and 492465 (North Arm) are available to derive the upstream boundary conditions of water quality constituents for the model.

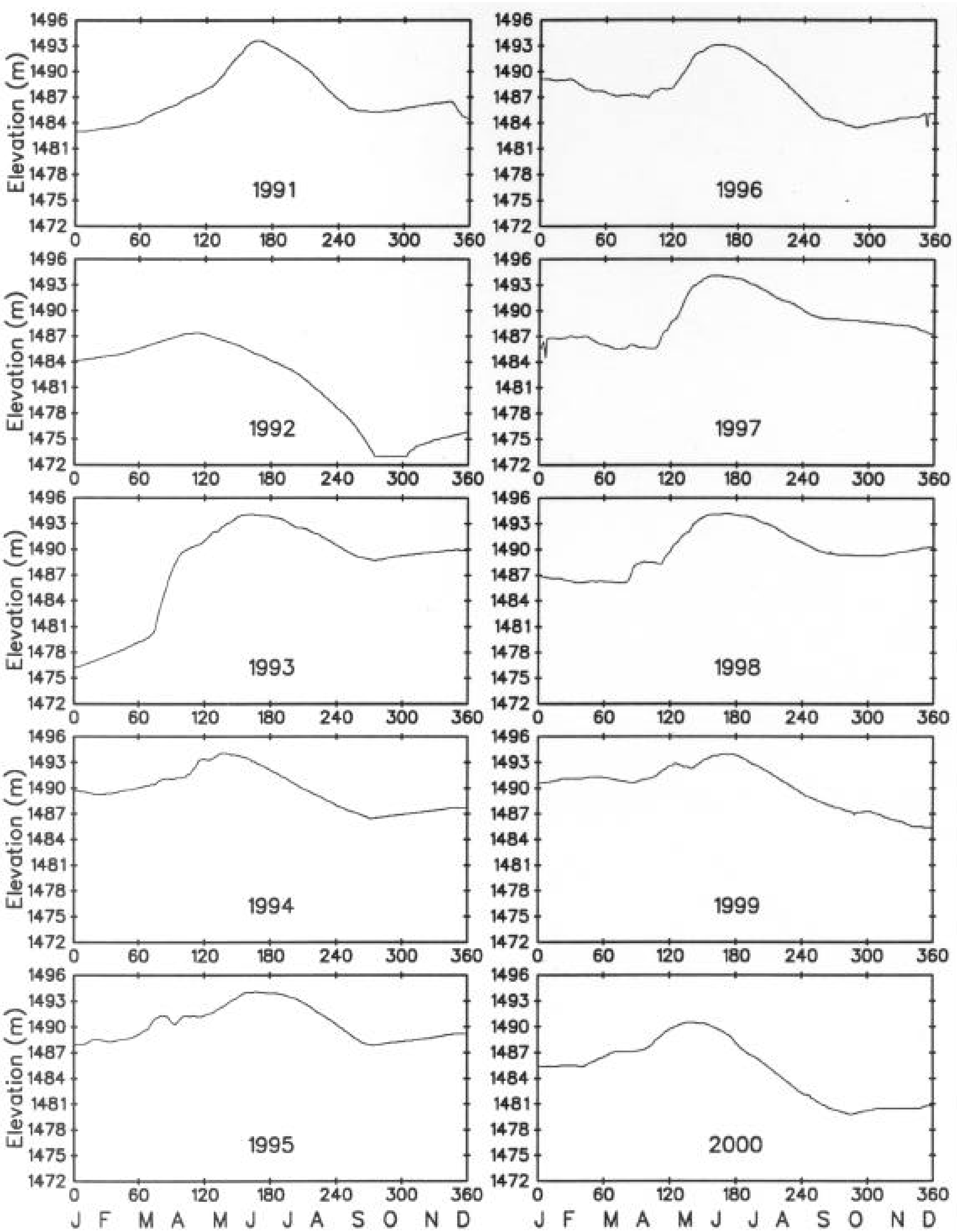

Figure 12. Observed surface elevation of Pineview Reservoir from 1991 to 2000 (USBR, 2001).

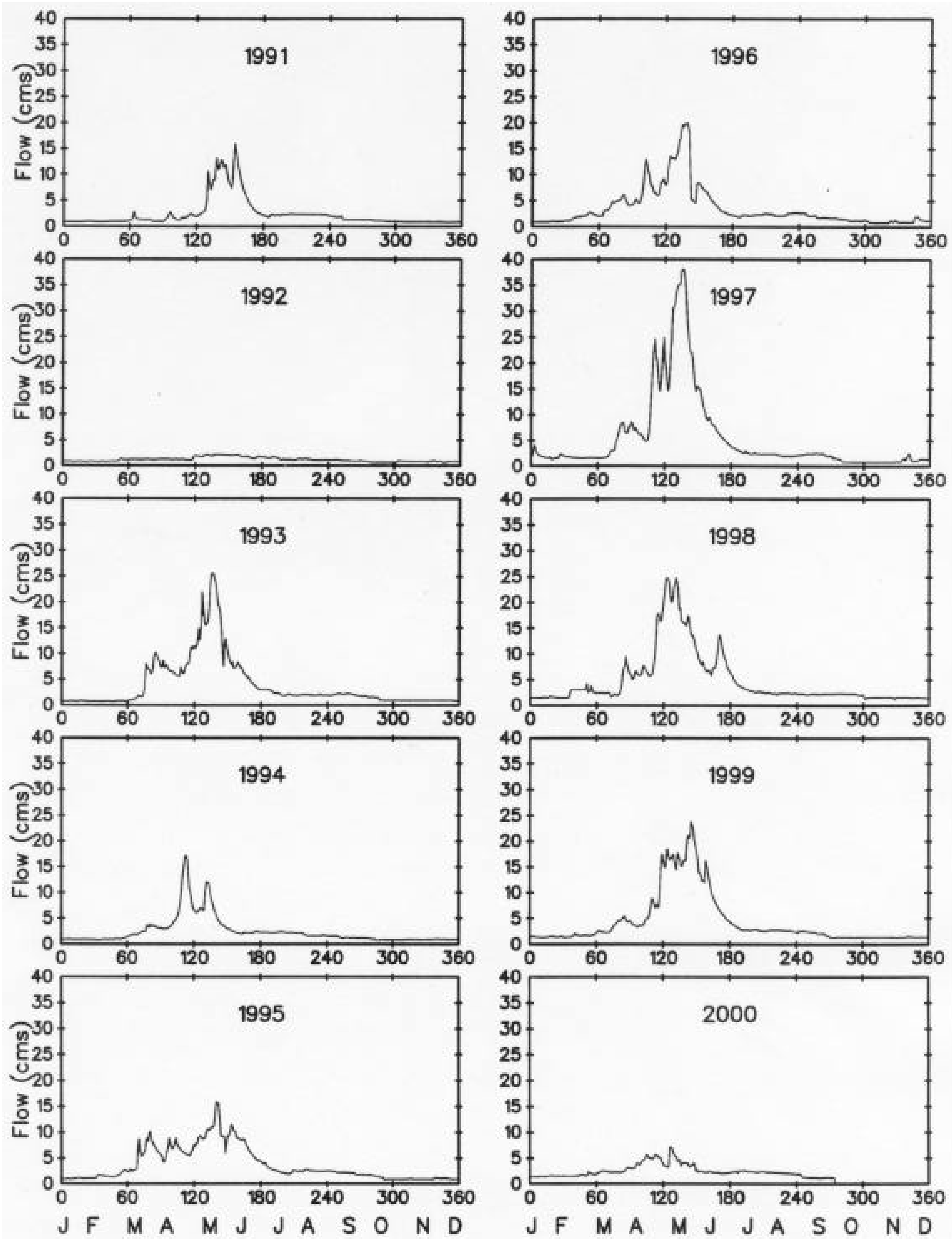

Figure 13. Inflow rates from the South Arm of Pineview Reservoir from 1991 to 2000 (USBR, 2001).

5.3 Hydrodynamic Model Calibration

The Pineview Reservoir is divided into 34 segments (including boundary segments) for a total of 3 branches: South, Middle, and North. Figure 14 displays the segmentation map provided by the USBR.

The inflow temperatures for these three branches were developed by USBR and are being used in this model calibration analysis. It should be pointed out that a 10-year model run was set up by USBR from 1991 to 2000. Due to the limiting extent of available data, it was determined to calibrate the W2 model of the Pineview Reservoir using the data from 1996, a year that was observed with lower than average flows. That is, the W2 model was configured to simulate the water column temperature for comparison with the 1996 data.

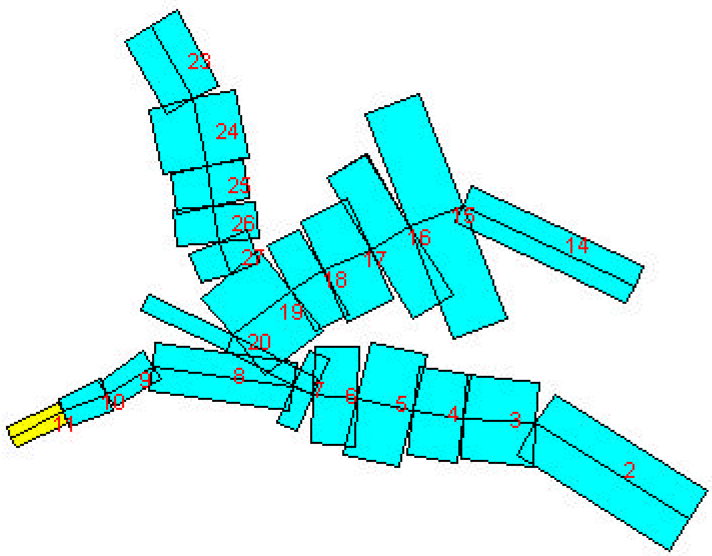

Figure 14. W2 model segmentation for Pineview Reservoir.

The first step of calibrating the hydrodynamic model is to assess the water balance in the reservoir for 1996. A special version of the W2 model was used to perform this analysis. The water balance is maintained in the model by matching the calculated reservoir elevations with the measured data and by quantifying the difference in inflow rates to the reservoir. Due to the uncertainty of groundwater inflows, this inflow difference would include the groundwater inflows. A series of water-balance calculations were conducted to check the time-variable reservoir volumes until the calculated volumes match the observed volumes. The residual flows from this analysis are incorporated into the model as distributed tributary flows. Such an approach is justified as many unknowns can be lumped together into one calibration parameter. Figure 15 shows the calculated versus measured surface elevations for 1996, indicating an excellent match between the model-calculated and the observed elevations, indicating an excellent water balance in the model. A similar result from the water balance calculation of 1998 shows a close match between the calculated and measured surface elevations with the water balance maintained.

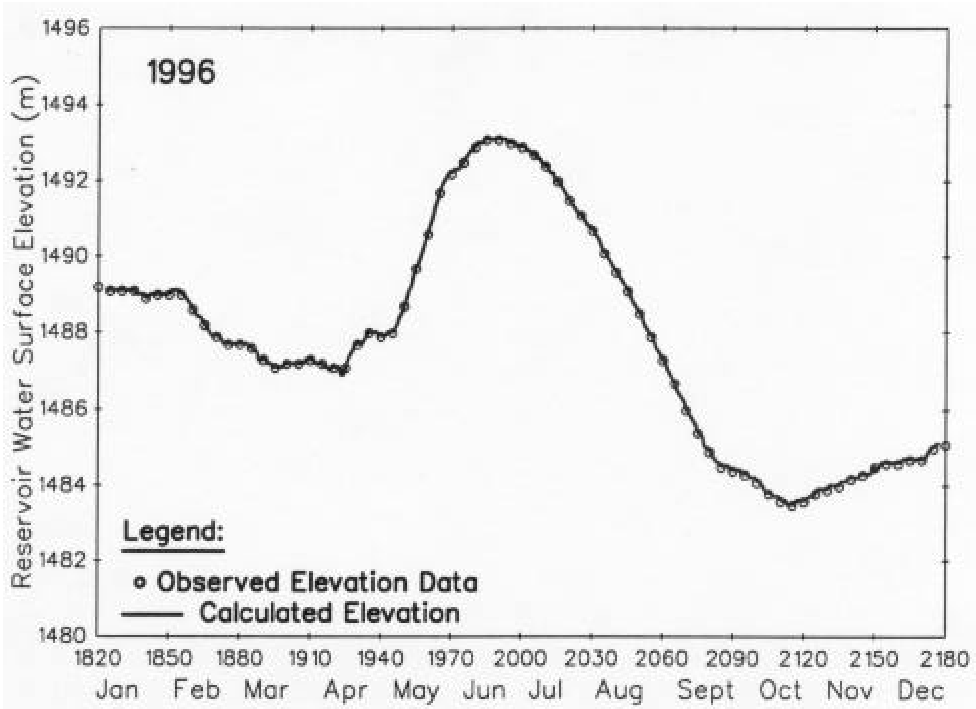

Figure 15. Model-calculated elevations vs. observed data of Pineview Reservoir in 1996.

The next step is comparing the calculated vertical profiles of temperature versus data at four stations: 492381, 492382, 492383, and 492384 on June 19 and August 6, 1996. The model results reproduced the temperature data well for both dates except the June 19, 1996 data at 492381 (above the dam) (Figure 16). As noted earlier in the report, the temperature profile at this station on June 19, 1996 is not consistent with the profiles usually observed in the water column at this time of the year. Instead, the model results show a more typical temperature profile, a progressive decrease of temperature with the depth, showing a shallow surface layer of uniform temperature.

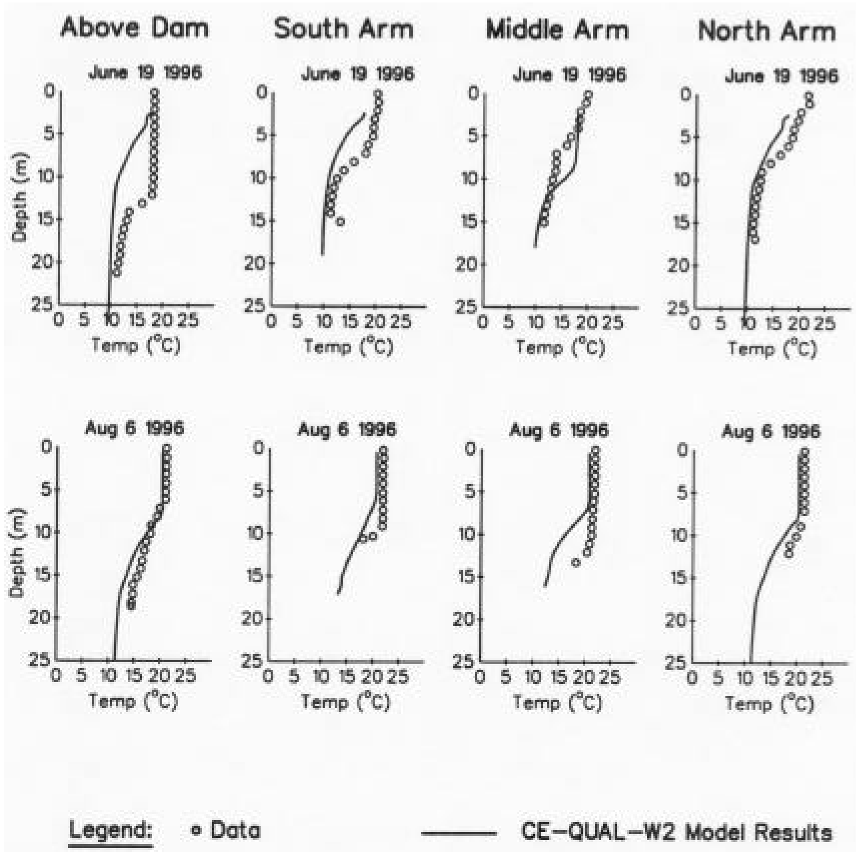

Figure 16. Model-calculated temperature vs. data on June 19 and August 6, 1996.

The hydrodynamic model was also calibrated with another year of data from 1998 to further substantiate its validity. The model was configured with the 1998 data to perform the whole-year simulation. Figure 17 shows the model calculated temperature profiles versus data at four stations in 1998. There are no temperature measurements at the three branch stations on July 23, 1998, leaving only one temperature profile (August 25, 1998) for comparison with the model results. In general, the measured temperature profiles are reproduced by the model. Also note the gradual decrease of temperatures with depth in the water column, which is typical for reservoirs of this size in this climate.

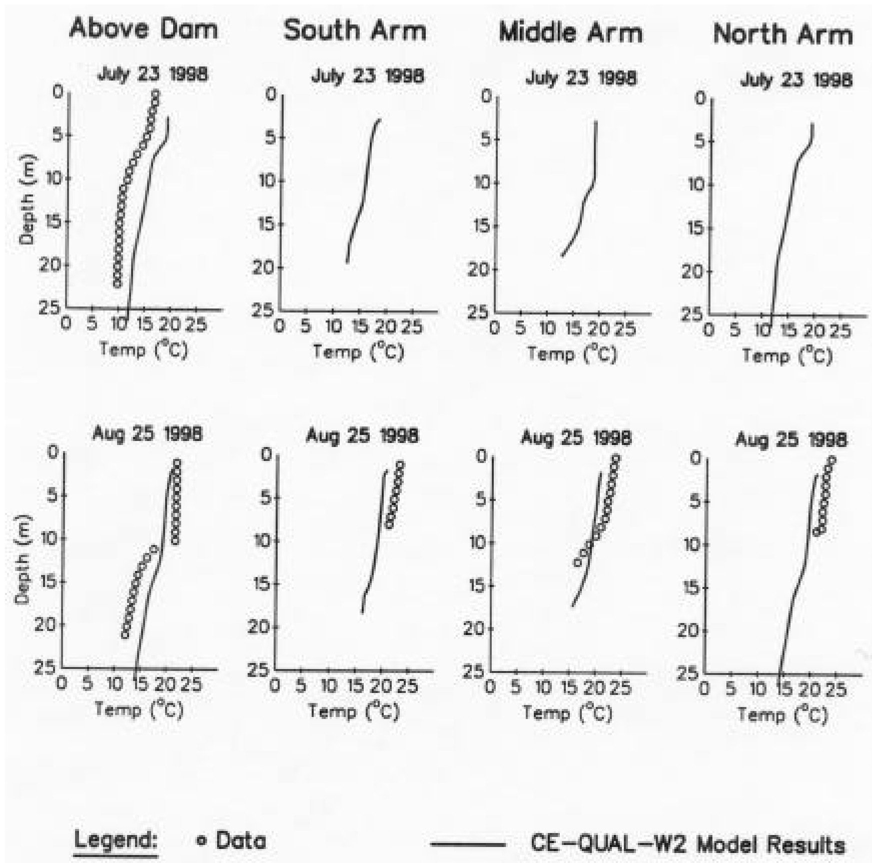

Figure 17. Model-calculated temperature vs. data on July 23 and August 25, 1998.

5.4 Water Quality Model Calibration

The calibrated hydrodynamic model was then configured to simulate the reservoir water quality in 1996. The following water quality constituents were simulated by the model: ultimate carbonaceous biochemical oxygen demand ($CBOD_u$), DO, TP, ammonia, nitrite/nitrate, and algae (carbon in biomass). While the model produced vertical profiles of these parameters on a time-variable basis, only the DO profiles are compared with the data to calibrate the water quality model, as data for vertical profiles of other water quality constituents are not available. Figure 18 shows the comparison of model calculated DO profiles versus observed profiles on June 19 and August 6, 1996 following a series of model calibration runs. The model results match the vertical DO profiles reasonably well. One of the key factors in calibrating the DO profiles is the sediment oxygen demand (SOD). SOD represents the rate at which organics in the sediment consume oxygen during decomposition. Following a series of model sensitivity runs, the SOD value is finalized as 0.9 grams carbon m^2 day^{-1} or equivalent to 2.40 mg oxygen m^2 day^{-1}, a reasonable value in reservoirs (Lung, 2001).

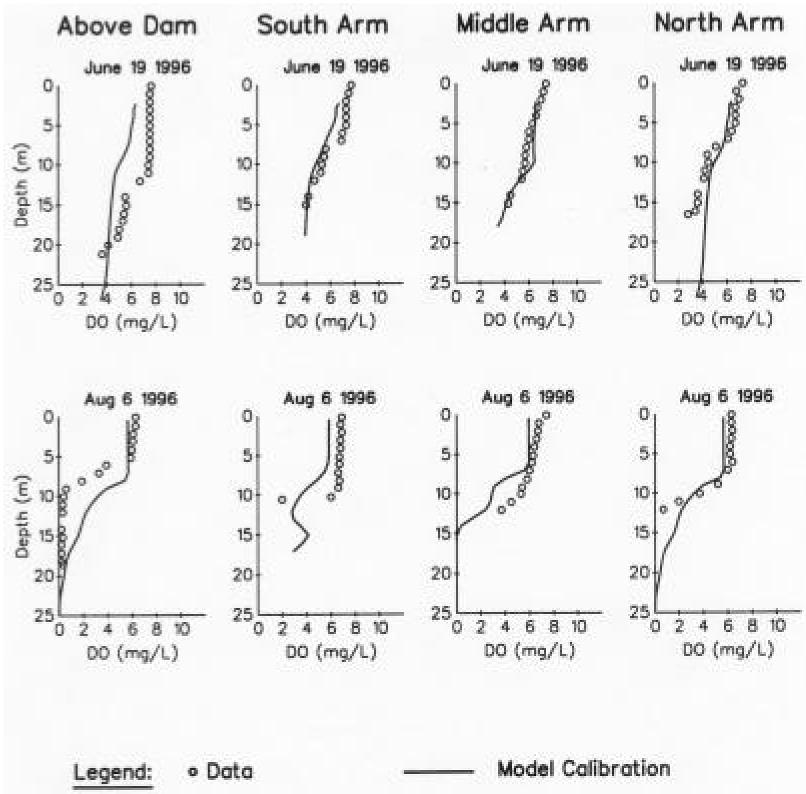

Figure 18. Model-calculated DO vs. data on June 19 and August 6, 1996.

6.0 TMDL

6.1 DO

The calibrated W2 model was used to identify the nutrient load reductions that are necessary to achieve the endpoint of 4.0 mg/L DO for at least 50 percent of the water column depth above Pineview Dam (see Section 3). The model was first run for all of 1996 to get a picture of year-long existing conditions. Figure 19 displays the daily percent depth greater than 4.0 mg/L for this year and shows that the endpoint is not met during the late summer months.

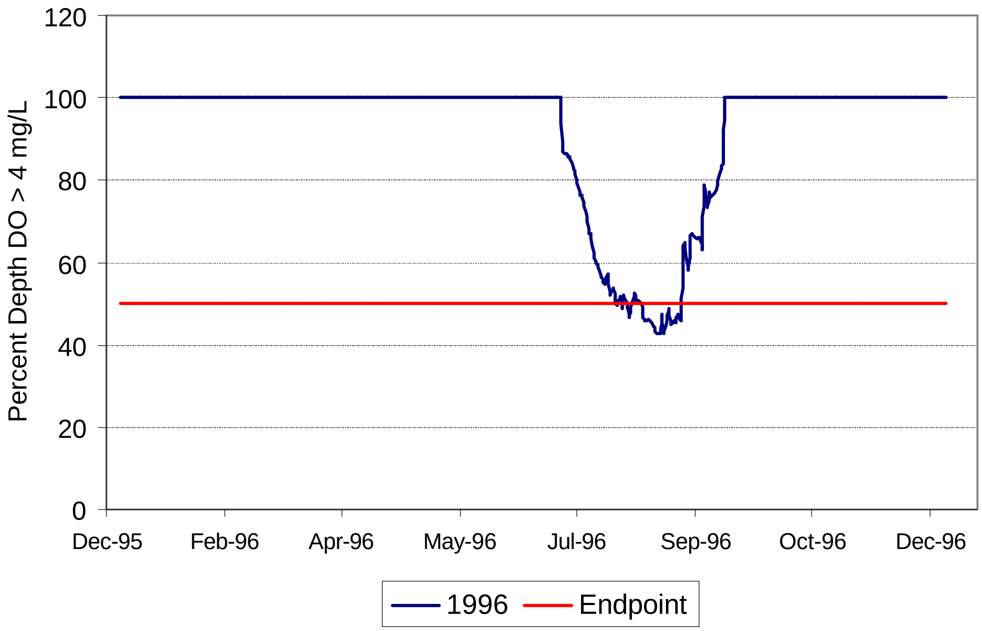

Figure 19. Percent of depth with DO greater than 4.0 mg/L in 1996.

The model was repeatedly run to identify scenarios that would achieve the desired endpoint. A 15 percent reduction in nutrients was determined necessary to meet the TMDL endpoint. Figure 20 displays the predicted DO conditions with a 15 percent reduction. The data and analysis completed for this TMDL could not conclusively identify if Pineview Reservoir was nitrogen- or phosphorus-limited. Accordingly, a 15 percent reduction in both nutrients was used to derive the DO response depicted in Figure 20.

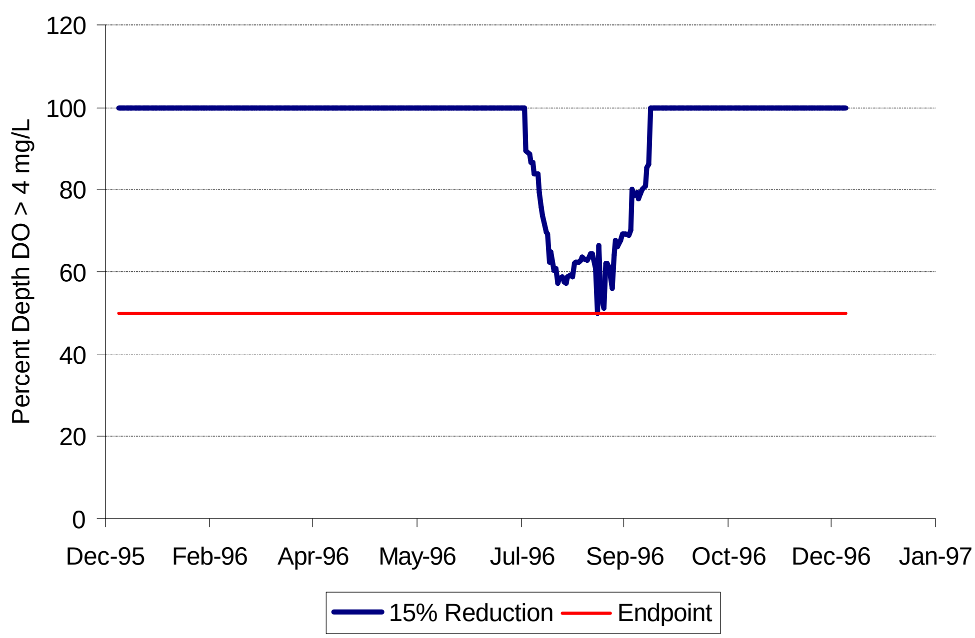

Figure 20. Percent of depth with DO greater than 4.0 mg/L after TMDL.

6.2 Temperature

The model was run to determine temperature conditions within Pineview Reservoir during 1996 and no violations of the 27 °C warm water criteria were predicted; however, many violations of the 20 °C cold water criteria were predicted (Figure 21). This matches the available sampling data.

Based on these results and the considerations explained below a TMDL for temperature is not being presented in this report. Instead, the Utah DEQ will undertake rulemaking to change the beneficial use from a cold water fishery to a warm water fishery. Two of the considerations supporting this change are:

- The reservoir is currently being successfully managed as a warm water fishery by the Division of Wildlife Resources. Pineview Reservoir is presently one of the best warm water fisheries in Utah. There is no desire by the Division of Wildlife Resources to manage the reservoir as a cold water fishery (Utah Division of Wildlife Resources, March 2002).
- There are limited reasonable options for altering the temperature conditions. One option would be to decrease the temperatures of inflows. However, groundwater temperatures are largely uncontrollable and the only significant source of surface water in the summer, the South Fork, is already fairly well shaded. Another option for addressing temperature issues would be to alter the management of the reservoir. However, altering the reservoir management could impair a valuable cold water fishery below the reservoir in Ogden River. Furthermore, reservoir management is principally governed by water rights (State Engineer).

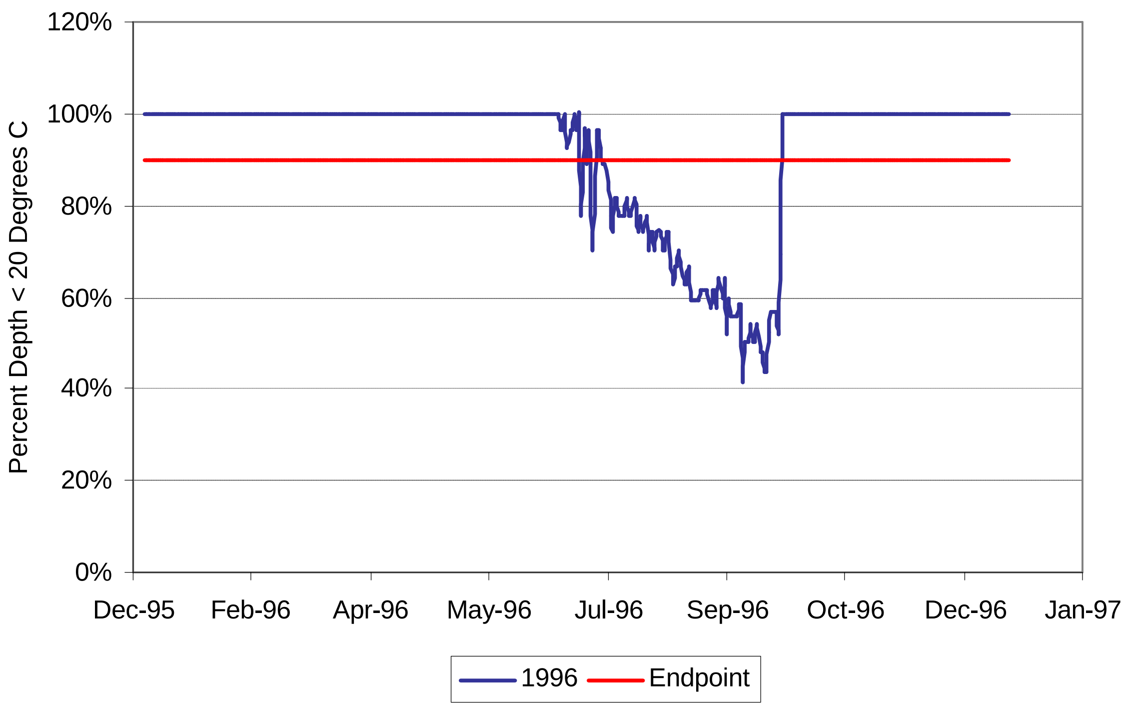

Figure 21. Percent of depth with temperature less than 20 ºC in 1996.

6.3 Algae

A target of this TMDL is to shift the algal dominance away from blue-green algae. This will be accomplished by the nutrient load reductions described elsewhere, which is predicted to result in less overall algal biomass as well as a shift towards more desirable species.

6.4 Phosphorus

The W2 model can only analyze for dissolved phosphorus. The modeling for Pineview indicates that an annual average dissolved phosphorus target of 0.05 mg/L above the dam will result in achievement of the DO standard. From prior experience with other reservoirs, 0.05 mg/L dissolved phosphorus appears higher than is advisable, particularly given some of the uncertainty involved in the modeling analysis. In addition, existing data meets the 0.05 mg/L level yet nutrient impairment exists. Accordingly, the phosphorus endpoint for this TMDL will be 0.025 mg/L TP.

7.0 SEASONALITY, MARGIN OF SAFETY, AND FUTURE GROWTH

7.1 Seasonality

Section 303(d)(1)(C) of the Clean Water Act and USEPA's regulations at 40 CFR 130.7(c)(1) require that a TMDL be established with seasonal variations. Seasonality is fully addressed in the Pineview Reservoir TMDL by using the SWAT and W2 models to predict daily loadings and reservoir water quality over a multiyear period using actual weather conditions. The estimated existing and allocated loads are therefore reflective of seasonal changes in weather and other conditions that can vary over the course of a year (e.g., reservoir management, irrigation practices). Load reductions are also targeted toward meeting water quality standards during the critical late summer period (August and September).

7.2 Margin of Safety

Section 303(d) of the Clean Water Act and USEPA's regulations at 40 CFR 130.7 require that "TMDLs shall be established at levels necessary to attain and maintain the applicable narrative and numerical water quality standards with seasonal variations and a margin of safety which takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality." The margin of safety can either be incorporated into conservative assumptions used to develop the TMDL or added as a separate component of the TMDL (USEPA, 1991).

A margin of safety has been incorporated into the Pineview Reservoir TMDL in several ways. First, the TMDL endpoint is based on percent depth of DO greater than 4.0 mg/L. In practice, the volume of the reservoir with at least 4.0 mg/L DO is much more meaningful to the aquatic life. Figure 22 indicates that a 15 percent reduction in nutrient loads will result in more than 90 percent of the volume of the reservoir always having at least 4.0 mg/L DO. A 5 percent explicit margin of safety has also been included within the TMDL to address the uncertainties associated with the modeling, especially the relative lack of tributary sampling and flow data with which to more accurately estimate existing loads and the shortage of reservoir water quality data with which to better calibrate the reservoir model.

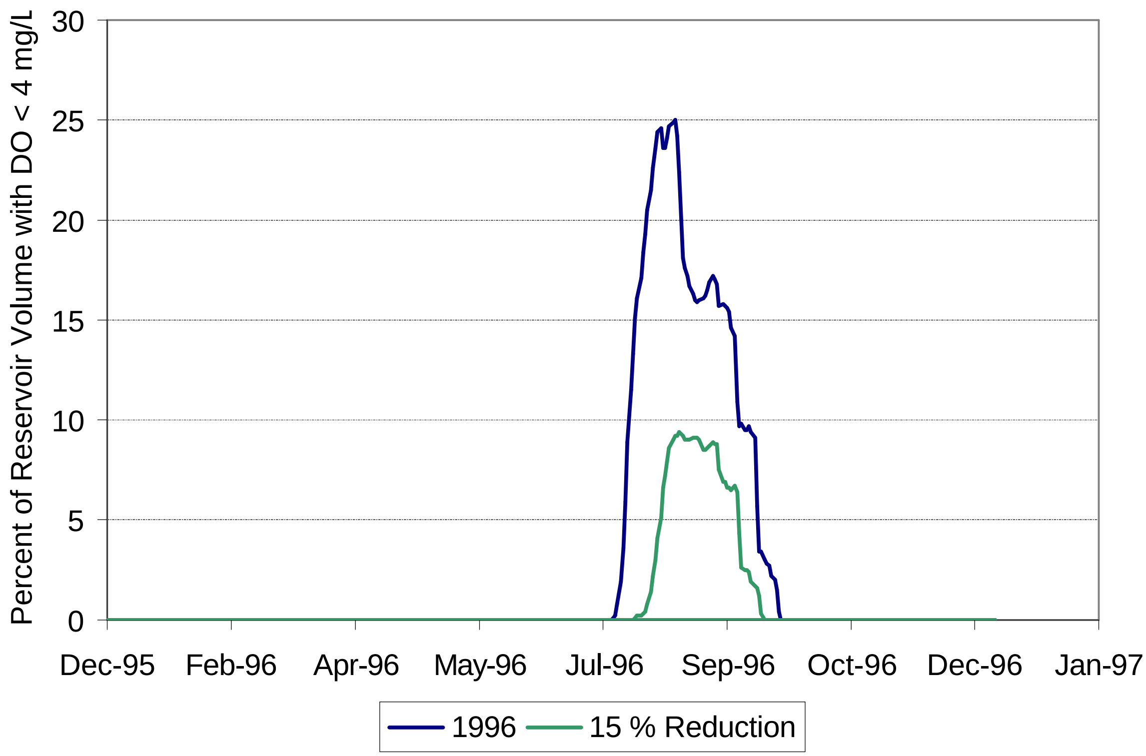

Figure 22. Percent of reservoir volume with DO concentrations less than 4.0 mg/L during 1996 and after 15 percent reduction.

7.3 Future Growth

Future growth within Ogden Valley is a significant issue, with population expected to continue to grow rapidly. Although the reservoir is generally in good shape now, it is very susceptible to continued growth because of the impact of wastewater on the groundwater aquifer and subsequently the reservoir.

For purposes of this draft TMDL a 5 percent reserve for future growth has been set aside. This will provide for continued growth but emphasizes that the impacts of all future growth must be fully addressed and nutrient loads minimized.

8.0 ALLOCATION OF LOAD REDUCTIONS

The loading capacity and allocation of loads for Pineview Reservoir are summarized in Table 25.

Table 25. TMDL summary for Pineview Reservoir.

Category	Dissolved Nitrogen (kg/yr)	Dissolved Phosphorus (kg/yr)
Existing load	118,133	7,920
Loading capacity	100,413	6,732
Wasteload allocation	0	0
Explicit margin of safety	5,021	337
Reserve for future growth	5,021	337
Load allocation	90,371	6,058
Necessary reduction	27,762	1,862

The load allocation indicates the need for reducing loads from nonpoint sources by approximately 24 percent. A distribution of these load reductions is provided below. The draft Project Implementation Plan (PIP)(Appendix A) provides more details on how load reductions will be achieved.

Table 26. Preliminary nonpoint source load allocations (annual loads in kg/yr).

Category	Current Nitrogen Load	TMDL Nitrogen Reduction	Post-TMDL Nitrogen Load	Current Phosphorus Load	TMDL Phosphorus Reduction	Post-TMDL Phosphorus Load
Groundwater	21,998	10,999	10,999	587	293	294
Onsite wastewater treatment systems	39,306	276	39,030	1,215	755	460
Tributary loadings	26,774	10,710	16,064	3,718	1,487	2,231
Animal wastes	30,055	7,514	22,541	2,400	600	1,800
Total	118,133	29,499	88,634	7,920	3,135[1]	4,785

[1] The measures needed to obtain the necessary load reductions for nitrogen result in reductions greater than the target of 1,862 kg/yr needed for phosphorus.

9.0 PUBLIC PARTICIPATION

The public participation process for this TMDL was addressed through the use of a series of public meetings and a local watershed committee. The Pineview Reservoir Steering Committee has been in operation for several years prior to this TMDL. The committee is comprised of individuals who represent a broad-based and diverse cross-section of the interested stakeholders in the watershed. All of the committee meetings are open to the public.

In addition the Division of Water Quality, in coordination with the Pineview Reservoir Steering Committee, held public meetings to provide information and education on the TMDL process and to take comments on the draft TMDL. The first meeting was held May 31, 2001 at the Huntsville Public Library. The second meeting was held August 9, 2001, also at the Huntsville Public Library. The primary purpose of these meetings was to advise the public that a TMDL was being compiled, present the issues to be considered and addressed, and outline the timeframes for developing the TMDL. Attendance at these two meetings was good with more than 23 people present at the first meeting and more than 10 at the second meeting. A final public meeting was held January 24, 2002 to discuss and take comments on the draft TMDL.

Furthermore, a 30-day public comment period, from January 17 through February 19, 2002, was advertised in the local newspaper (*Ogden Valley News,* January 15, 2002 edition) as well as on the Division of Water Quality's web site. Draft TMDL reports were made available to the public at the local library as well as from the division's web site. No written comments were received during the 30-day comment period.

10.0 FUTURE RECOMMENDATIONS

The Pineview Reservoir TMDL was compiled using the best data available. As in virtually all TMDLs completed to date in Utah, a degree of uncertainty exists based on the less than perfect data set used to complete this analysis. Having completed the initial analysis, the following recommendations should be undertaken to gather additional data, track attainment of defined endpoints, and adjust the TMDL, if sufficient new data warrants modification.

1. Supplemental monitoring should be undertaken during the next year or 2 to refine the understanding and confirm the analysis completed for this study:
    a. Monthly groundwater inflows from significant inflow points should be monitored around the reservoir during the irrigation season and after the irrigation season has ceased (June–November).
    b. Sampling of the reservoir to include lake profiles of temperature, DO, pH, conductivity, and nutrient samples at four intervals and chlorophyll a in the profile should be undertaken at least monthly from June through October.
    c. Monthly sampling of tributary flows and water quality should be completed to confirm tributary loading estimates.

2. Inventory information for Completed Animal Feeding Operations (AFO) and Concentrated Animal Feeding Operations (CAFO) should be obtained to confirm animal waste loading calculations. Nutrient management plans for each operation should be compiled to provide detailed cost information for the PIP (Appendix A).

3. The project PIP, Appendix A, should be undertaken to effect the needed changes to improve water quality and restore and maintain the beneficial uses of Pineview Reservoir.

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